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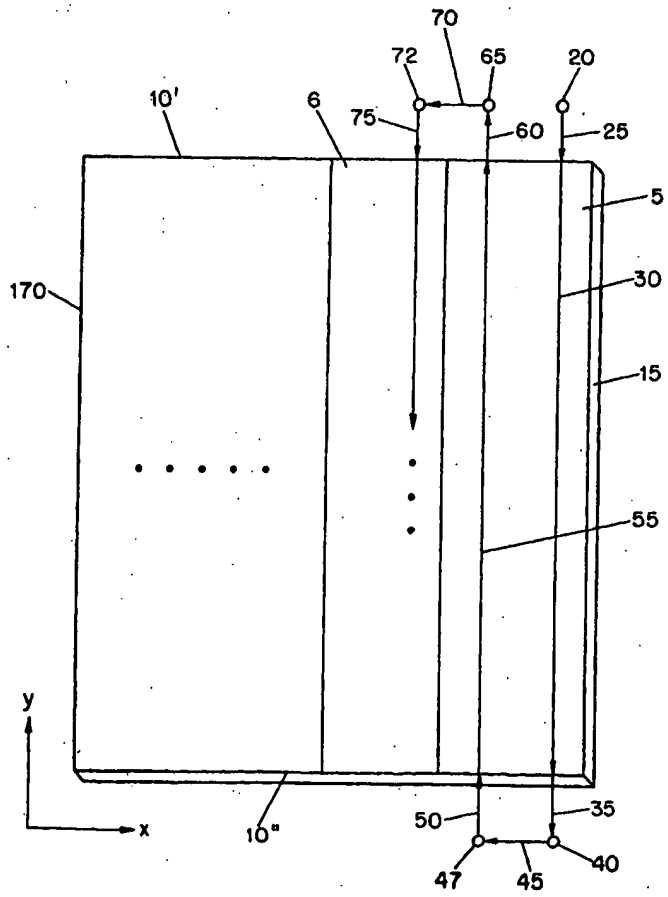

(57) Abstract: A method and system for processing an amorphous silicon thin film sample to produce a large grained, grain boundary-controlled silicon thin film. The film sample includes a first edge and a second edge. In particular, using this method and system, an excimer laser is used to provide a pulsed laser beam, and the pulse laser beam is masked to generate patterned beamlets, each of the patterned beamlets having an intensity which is sufficient to melt the film sample. The film sample is continuously scanned at a first constant predetermined speed along a first path between the first edge and the second edge with the patterned beamlets. In addition, the film sample is continuously scanned at a second constant predetermined speed along a second path between the first edge and the second edge with the patterned beamlets.

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METHOD AND SYSTEM FOR PROVIDING A CONTINUOUS MOTION SEQUENTIAL LATERAL SOLIDIFICATION

SPECIFICATION

FIELD OF THE INVENTION

The present invention relates to a method and system for processing a thin-film semiconductor material, and more particularly to forming large-grained grain boundary-location controlled semiconductor thin films from amorphous or polycrystalline thin films on a substrate using laser irradiation and a continuous motion of the substrate having the semiconductor film being irradiated.

BACKGROUND INFORMATION

In the field of semiconductor processing, there have been several attempts to use lasers to convert thin amorphous silicon films into polycrystalline films. For example, in James Im et al., "Crystalline Si Films for Integrated Active-Matrix Liquid-Crystal Displays," 11 MRS Bulletin 39 (1996), an overview of conventional excimer laser annealing technology is described. In such conventional system, an excimer laser beam is shaped into a long beam which is typically up to 30 cm long and 500 micrometers or greater in width. The shaped beam is stepped over a sample of amorphous silicon to facilitate melting thereof and the formation of grain boundary-controlled polycrystalline silicon upon the resolidification of the sample.

The use of conventional excimer laser annealing technology to generate polycrystalline silicon is problematic for several reasons. First, the polycrystalline silicon generated in the process is typically small grained, of a random micro structure (i.e., poor control of grain boundaries), and having a nonuniform grain sizes, therefore resulting in poor and nonuniform devices and accordingly, low manufacturing yield. Second, in order to obtain acceptable quality grain boundary-controlled polycrystalline thin films, the manufacturing throughput for producing such thin films must be kept low. Also, the process generally requires a controlled atmosphere and preheating of the amorphous

silicon sample, which leads to a reduction in throughput rates. Accordingly, there exists a need in the field to generate higher quality thin polycrystalline silicon films at greater throughput rates. There likewise exists a need for manufacturing techniques which generate larger and more uniformly microstructured polycrystalline silicon thin films to be used in the fabrication of higher quality devices, such as thin film transistor arrays for liquid crystal panel displays.

SUMMARY OF THE INVENTION

An object of the present invention is to provide techniques for producing large-grained and grain boundary location controlled polycrystalline thin film semiconductors using a sequential lateral solidification process and to generate such silicon thin films in an accelerated manner.

At least some of these objects are accomplished with a method and system for processing an amorphous or polycrystalline silicon thin film sample into a grain boundary-controlled polycrystalline thin film or a single crystal thin film. The film sample includes a first edge and a second edge. In particular, using this method and system, a laser beam generator is controlled to emit a laser beam, and portions of this laser beam are masked to generate patterned beamlets, each of the beamlets having an intensity which is sufficient to melt the film sample. The film sample is continuously scanned at a first constant predetermined speed along a first path between the first edge and the second edge by the patterned beamlets. In addition, the film sample is continuously scanned at a second constant predetermined speed along a second path between the first edge and the second edge by the patterned beamlets.

In another embodiment of the present invention, the film sample is continuously translated in a first direction so that the fixed patterned beamlets continuously irradiate successive first portions of the film sample along the first path. The first portions are melted while being irradiated. In addition, the film sample is continuously translated in a second direction so that the fixed patterned beamlets irradiate successive second portions of the film sample along the second path. The second portions are melted while being irradiated. Furthermore, after the film sample is translated in the first direction to irradiate a next successive portion of the first path of the film sample,

the first portions are cooled and resolidified, and after the film sample is translated in the second direction to irradiate a next successive portion of the second path of the film sample, the second portions are cooled and resolidified.

In yet another embodiment of the present invention, the film sample is positioned so that the patterned beamlets impinge at a first location outside of boundaries of the film sample with respect to the film sample. Also, the film sample can be microtranslated from the first location to a second location before the film sample is scanned along the second path, starting from the second location.

In a further embodiment of the present invention, after the film sample is scanned along the second path, the film sample is translated so that the beamlets impinge a third location which is outside the boundaries of the film sample microtranslated. Thereafter, the film sample can be stepped so that the impingement of the beamlets moves from the third location to a fourth location, the fourth location being outside of the boundaries of the film sample. Then, the film sample is maintained with the patterned beamlets impinging on the fourth location until the film sample stops vibrating and after the movement of the film sample ceases.

In another embodiment of the present invention, the film sample is continuously scanned in a first direction so that the fixed position beamlets scan the first path, and then in a second direction so that the fixed position beamlets scan the second path. After the film sample is translated in the first direction, it is continuously translated at the first constant predetermined speed in a second direction so that the patterned beamlets irradiate the first successive portions of the film sample along the second path, the second direction being opposite to the first direction. Then, the film sample is microtranslated so that the impingement of the beamlets moves from the first location to a second location, the second location being outside of boundaries of the film sample. Thereafter, the film sample is continuously translated at the second constant predetermined speed in a first direction so that the patterned beamlets irradiate second successive portions of the film sample along the second path until the beamlets impinge on the second location, the first direction being opposite to the second direction.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1a shows a diagram of an exemplary embodiment of a system for performing a continuous motion solidification lateral solidification ("SLS") according to the present invention.

Fig. 1b shows an embodiment of a method according of the present invention for providing the continuous motion SLS which may be utilized by the system of Fig. 1a.

Fig. 2a shows a diagram of a mask having a dashed pattern.

Fig. 2b shows a diagram of a portion of a crystallized silicon film resulting from the use of the mask shown in Fig. 2a in the system of Fig. 1a.

Fig. 3a shows a diagram of a mask having a chevron pattern.

Fig. 3b shows a diagram of a portion of a crystallized silicon film resulting from the use of the mask shown in Fig. 3a in the system of Fig. 1a.

Fig. 4a shows a diagram of a mask having a line pattern.

Fig. 4b shows a diagram of a portion of a crystallized silicon film resulting from the use of the mask shown in Fig. 4a in the system of Fig. 1a.

Fig. 5a shows an illustrative diagram showing portions of irradiated areas of a silicon sample using a mask having the line pattern.

Fig. 5b shows an illustrative diagram of the portions of the irradiated areas of a silicon sample using a mask having a line pattern after initial irradiation and sample translation has occurred, and after a single laser pulse during the method illustrated in Fig. 1b.

Fig. 5c shows an illustrative diagram of the portions of the crystallized silicon film after a second irradiation has occurred which was generated using the method illustrated in Fig. 1b.

Fig. 6a shows a mask having a diagonal line pattern.

Fig. 6b a diagram of a portion of a crystallized silicon film resulting from the use of the mask shown in Fig. 6a in the system of Fig. 1a;

Fig. 7 shows another embodiment of a method according of the present invention for providing the continuous motion SLS which may be utilized by the system

of Fig. 1a.

Fig. 8 shows a flow diagram illustrating the steps implemented by the method illustrated in Fig. 1b.

DETAILED DESCRIPTION

The present invention provides techniques for producing uniform large-grained and grain boundary location controlled crystalline thin film semiconductors using the sequential lateral solidification process. In order to fully understand those techniques, the sequential lateral solidification process must first be appreciated.

The sequential lateral solidification process is a technique for producing large grained silicon structures through small-scale unidirectional translation of a sample in having a silicon film between sequential pulses emitted by an excimer laser. As each pulse is absorbed by the silicon film, a small area of the film is caused to melt completely and resolidify laterally into a crystal region produced by the preceding pulses of a pulse set.

An advantageous sequential lateral solidification process and an apparatus to carry out that process are disclosed in co-pending patent application no. 09/390,537 (the "'537 application") filed on September 3, 1999, and assigned to the common assignee, the entire disclosure of which is incorporated herein by reference. While the foregoing disclosure is made with reference to the particular techniques described in the '537 application, it should be understood that other sequential lateral solidification techniques could easily be adapted for the use in the present invention.

Fig. 1a shows a system according to the present invention which is capable of implementing the continuous motion SLS process. As also described in the '537 application, the system includes an excimer laser 110, an energy density modulator 120 to rapidly change the energy density of a laser beam 111, a beam attenuator and shutter 130 (which is optional in this system), optics 140, 141, 142 and 143, a beam homogenizer 144, a lens and beam steering system 145, 148, a masking system 150, another lens and beam steering system 161, 162, 163, an incident laser pulse 164, a thin silicon film sample on a substrate 170, a sample translation stage 180, a granite block 190, a support system 191, 192, 193, 194, 195, 196, and a computer 100 which manages X and Y

direction translations and microtranslations of the silicon film sample and substrate 170. The computer 100 directs such translations and/or microtranslations by either a movement of a mask within masking system 150 or by a movement of the sample translation stage 180.

As described in further detail in the '537 application, an amorphous silicon thin film sample is processed into a single or polycrystalline silicon thin film by generating a plurality of excimer laser pulses of a predetermined fluence, controllably modulating the fluence of the excimer laser pulses, homogenizing the modulated laser pulses in a predetermined plane, masking portions of the homogenized modulated laser pulses into patterned beamlets, irradiating an amorphous silicon thin film sample with the patterned beamlets to effect melting of portions thereof irradiated by the beamlets, and controllably translating the sample with respect to the patterned beamlets and with respect to the controlled modulation to thereby process the amorphous silicon thin film sample into a single or grain boundary-controlled polycrystalline silicon thin film by the sequential translation of the sample relative to the patterned beamlets and irradiation of the sample by patterned beamlets of varying fluence at corresponding sequential locations thereon. The following embodiments of the present invention will now be described with reference to the foregoing processing technique.

Fig. 1b shows an embodiment of a process according of the present invention for providing the continuous motion SLS which may utilize the system described above. In particular, the computer 100 controls the motion (in the planar X-Y direction) of the sample translation stage 180 and/or the movement of the masking system 150. In this manner, the computer 100 controls the relative position of the sample 170 with respect to the pulsed laser beam 149 and the final pulsed laser beam 164. The frequency and the energy density of the final pulsed laser beam 164 are also controlled by the computer 100.

As described in co-pending patent application no. 09/390,535 (the "'535 application") filed on September 3, 1999, and also assigned to the common assignee, the entire disclosure of which is incorporated herein by reference, the sample 170 may be translated with respect to the laser beam 149, either by moving the masking system 150 or the sample translation stage 180, in order to grow crystal regions in the sample 170.

For example, for the purposes of the foregoing, the length and width of the laser beam 149 may be 2cm in the X-direction by ½cm in the Y-direction (e.g., a rectangular shape), but the pulsed laser beam 149 is not limited to such shape and size. Indeed, other shapes and/or sizes of the laser beam 149 are, of course, achievable as is known to those having ordinary skill in the art (e.g., square, triangle, etc.).

Various masks may also be utilized to create the final pulsed laser beam and beamlets164 from the transmitted pulsed laser beam 149. Some examples of the masks are shown in Figs. 2a, 3a, 4a and 6a, a detailed description of which has already been provided in the '535 application. For example, Fig. 2a shows a mask 210 incorporating a regular pattern of slits 220, Fig. 3a shows a mask 310 incorporating a pattern of chevrons 320, and Fig. 6a shows a mask 610 incorporating a pattern of diagonal lines 620. For the sake of simplicity, provided below is a description of the process accordingly to the present invention which utilizes a mask 410 (shown in Fig. 4a) incorporating a pattern of slits 410, each of which may extend as far across on the mask 410 as the homogenized laser beam 149 incident on the mask 410 permits, and should have a width 440 that is sufficiently narrow to prevent any nucleation from taking place in the irradiated region of the sample 170. As discussed in the '535 application, the width 440 may depend on a number of factors, e.g., the energy density of the incident laser pulse, the duration of the incident laser pulse, the thickness of the silicon thin film sample, the temperature and thermal conductivity of the silicon substrate, etc.

In the exemplary embodiment shown in Fig. 1b, the sample 170 has the size of 40cm in the Y-direction by 30cm in the X-direction. The sample 170 is conceptually subdivided into a number of columns (e.g., a first column 5, a second column 6, etc.), and the location/dimension of each column is stored in a storage device of the computer 100, and utilized by the computer 100 . Each of the columns is dimensioned, e.g., 2cm in the X-direction by 40cm in the Y-direction. Thus, the sample 170 may be conceptually subdivided into, e.g., fifteen columns. It is also conceivable to conceptually subdivide the sample 170 into columns having different dimensions (e.g., 3cm by 40cm columns, etc.). When the sample 170 is conceptually subdivided into columns, at least a small portion of one column extending for the entire length of such column should be overlapped by a portion of the neighboring column to avoid a

possibility of having any unirradiated areas. For example, the overlapped area may have a width of, e.g., 1μm.

After the sample 170 is conceptually subdivided, a pulsed laser beam 111 is activated (by actuating the excimer laser using the computer 100 or by opening the shutter 130) and produces the pulsed laser beamlets 164 impinging on a first location 20 (from the pulsed laser beam 149). Then, the sample 170 is translated and accelerated in the forward Y-direction under the control of the computer 100 to reach a predetermined velocity with respect to the fixed position beamlets in a first beam path 25. Using the equation:

$$Vmax = Bw \cdot f,$$

where Vmax is a maximum possible velocity that the sample 170 can be moved with respect to the pulsed beamlets 164, Bw is the width of the pattern of the pulsed laser beamlets 164 (or the width of the envelope of the pulsed beamlets 164), and f is the frequency of the pulsed beamlets 164, the predetermined velocity Vpred can be determined using the following:

$$Vpred = Vmax - K,$$

where K is a constant, and is utilized to avoid a possibility of having any unirradiated areas between adjacent irradiated areas. It is also possible to use the system according to the present invention illustrated in Fig. 1a without utilizing the beam attentuator and shutter 130, since (as described below) due to the continuous translation of the sample 170, the pulsed beamlets 164 does not have to be blocked or turned off.

The pulsed beamlets 164 reach an upper edge 10' of the sample 170 when the velocity of the movement of the sample 170 with respect to the pulsed laser beam 149 reaches the predetermined velocity Vpred. Then, the sample 170 is continuously (i.e., without stopping) translated in the forward Y-direction at the predetermined velocity Vpred so that the pulsed beamlets 164 continue irradiating successive portions of the sample 170 for an entire length of a second beam path 30. When the pulsed beamlets 164 reach a lower edge 10" of the sample 170, the translation of the sample 170 is slowed with respect to the pulsed beamlets 164 (in a third beam path 35) to reach a second location 40. After the pulsed beamlets 164 continuously and sequentially irradiated the successive portions of the sample 170 along the second beam path 30, these successive

portions of the sample 170 are fully melted. It should be noted that after the pulsed beamlets 164 pass the lower edge 10" of the sample 170, a crystalized silicon thin film area 540 (e.g., grain boundary-controlled polycrystalline silicon thin film) forms in the irradiated second beam path 30 area of the sample 170, a portion of which is shown in Fig. 5b. This grain boundary-controlled polycrystalline silicon thin film area 540 extends for the entire length of the second irradiated beam path 30. It should be noted that it is not necessary to shut down the pulsed laser beam 149 after the pulsed beamlets 164 have crossed the lower edge 10" of the sample 170 because it is no longer irradiating the sample 170.

Thereafter, to eliminate the numerous small initial crystals 541 that form at melt boundaries 530 and while the location along the Y-direction of the pulsed beamlets 164 is fixed, the sample 170 is microtranslated for a predetermined distance (e.g., 3 micrometers) in the X-direction along a fourth beam path 45 to reach a third location 47, and is then accelerated in the reverse Y-direction (toward the top edge 10' of the sample 170) under the control of the computer 100 to reach the predetermined velocity of translation with respect to the pulsed beamlets 164 along a fourth beam path 50. The pulsed beamlets 164 reach the lower edge 10" of the sample 170 when the velocity of the sample 170 with respect to the pulsed beamlets 164 reaches the predetermined velocity Vpred. The sample 170 is continuously translated (i.e., without stopping) in the reverse Y-direction at the predetermined velocity Vpred so that the pulsed beamlets 164 irradiate the sample 170 for the entire length of a fifth beam path 55. When the sample 170 is translated under the control of the computer 100 so that the pulsed beamlets 164 reach the upper edge 10' of the sample 170, the continuous translation of the sample 170 is again slowed with respect to the pulsed beamlets 164 (in a sixth beam path 60) to reach a fourth location 65. The result of such irradiation of the fifth beam path 55 is that regions 551, 552, 553 of the sample 170 (shown in Fig. 5b) cause the remaining amorphous silicon thin film 542 and the initial crystallized regions 543 of the polycrystalline silicon thin film area 540 to melt, while leaving the central section 545 of the polycrystalline silicon thin film to remain solidified. After the pulsed beamlets 164 continuously and sequentially irradiated the successive portions of the sample 170 along the fifth beam path 55, these successive portions of the sample 170 are

fully melted. Thus, as a result of the laser beam 149's continuous (i.e., without a stoppage) irradiation of the first column 5 for its entire length in the fifth beam path 55, the crystal structure which forms the central section 545 outwardly grows upon solidification of melted regions 542, 542 of the thin film which were formed as a result of the continuous irradiation along the second beam path 30. Thus, a directionally controlled long grained polycrystalline silicon thin film is formed on the sample 170 along the entire length of the fifth beam path 55. A portion of such crystallized structure is illustrated in Fig. 5c. Therefore, using the continuous motion SLS procedure described above, it is possible to continuously form the illustrated crystallized structure along the entire length of the column of the sample 170.

Then, the sample 170 is stepped to the next column 6 to reach a fifth location 72 via a seventh beam path 70, and the sample is allowed to settle at that location to allow any vibrations of the sample 170 that may have occurred when the sample 170 was stepped to the fifth location 72 to cease. Indeed, for the sample 170 to reach the second column 6, it is stepped approximately 2cm for the columns having a width (in the X-direction) of 2cm. The procedure described above with respect to the irradiation of the first column 5 may then be repeated for the second column 6. In this manner, all columns of the sample 170 can be properly irradiated with only a minimal settling time which may be required for the sample 170 to settle (and thus wait for the vibrations of the sample 170 to stop). Indeed, the only time that may be required for settling the sample 170 is when the laser has completed the irradiation of an entire column (e.g., the first column 5) of the sample 170, and the sample 170 is stepped to the next column (e.g., the second column 6) of the sample 170. Using the exemplary dimensions of the sample 170 described above (30cm by 40cm), since each column is dimensioned 2cm by 40cm, there are only 15 columns that must be irradiated for this exemplary sample 170. Accordingly, the number of "step and settle" delays that may occur for the exemplary sample 170 is either 14 or 15.

To illustrate the time savings in using the continuous motion SLS procedure according to the present invention for producing the crystallized silicon thin film, it is possible that the time it takes to translate the sample 170 (which has the sample, column and laser beam dimensions discussed above) for the entire lengths in the various

travel paths of the sample 170 is estimated below:

the first beam path25 -	0.1 seconds,
the second beam path 30 -	0.5 seconds (since the sample 170 does not have to stop and settle for the entire length of a column, and translates continuously),
the third beam path 35 -	0.1 seconds,
the fourth beam path 45 -	0.1 seconds,
the fifth beam path 50 -	0.1 seconds,
the sixth beam path 55 -	0.5 seconds (again because the sample 170 does not have to stop and settle for the entire length of a column, and translates continuously),
the seventh beam path 60 -	0.1 seconds, and
the eight beam path 70 -	0.1 seconds.

Thus, the total time that it takes to completely irradiate each column 5, 6 of the sample is 1.6 seconds (or at most, e.g., 2 seconds). Thus, for 15 columns of the sample 170, the total time that it takes to form the grain boundary-controlled polycrystalline structure thin film (for the entire sample 170) is approximately 30 seconds.

As indicated above, it is also possible to use different dimensions and/or shapes for cross-sectional area of the laser beam 149. For example, it is possible to use the pulsed laser beam 149 which has the cross-sectional area dimensioned 1cm by 1cm (i.e., a square shape). It should be appreciated that it is advantageous to use the diameter of the pulsed beamlets 164 as one of the dimension parameters of the columns. In this instance, the 30cm by 40cm sample 170 may be conceptually subdivided into 30 columns, each column being dimensioned 1cm in the X-direction by 40 cm in the Y-direction (assuming a cross-section of a diameter of the pattern of the pulsed beamlets 164 of 1cm). Using such a pattern of the pulsed beamlets 164, it may be possible to increase the predetermined velocity Vpred for translating the sample 170, and possibly decrease the total energy of the pulsed laser beam 149. In this manner, instead of

irradiating the sample via 15 columns, the system and method according to the present invention would irradiate the sample via 30 columns. Even though it may take longer to step and settle from column to column for 30 columns (as opposed to 15 columns described above), the speed of the sample translation may be increased because, due to the column's smaller width, the intensity of the pulsed laser beam 149 can be greater, as a result of concentrating the laser pulse energy into a smaller beamlet pattern, to provide effective crystallization of the sample 170, and the total time to complete the irradiation of the sample 170 may not be significantly higher than that for the sample which has 15 columns.

According to the present invention, any mask described and shown in the '535 application may be used for the continuous motion SLS procedure illustrated in Fig. 1b. For example, when the mask 310 is used in masking system 150, a processed sample (i.e., a portion 350 shown in Fig. 3b having crystallized regions 360) is produced. Each crystal region 360 will consist of a diamond shaped single crystal region 370 and two long grained, directionally controlled grain boundary polycrystalline silicon regions 380 in the tails of each chevron. One may also use a mask 610 (shown in Fig. 6a) incorporating a pattern of diagonal slits 620. For this mask 610, when the sample 170 is continuously translated in the Y-direction, and the mask 610 is used in the masking system 150 of Fig. 1a, a processed sample (a portion 650 shown in Fig. 6b having crystallized regions 660) is produced. Each crystallized region 660 will consist of long grained, crystalline regions with directionally-controlled grain boundaries 670.

It is also possible to irradiate the sample 170 along the columns which are not parallel to the edges of the square sample 170. For example, the columns may extend at approximately 45 degree angle with respect to the edges of the sample 170. The computer 100 stores start and end points of each column and is capable of performing the procedure shown in Fig. 1b along parallel columns which are slanted at, e.g., 45 degrees with respect to the edges of the sample 170. The sample 170 can also be irradiated along parallel columns which are slanted at other angles with respect to the edges of the sample 170 (e.g., 60 degrees, 30 degrees, etc.).

In another exemplary embodiment of the method according to the present invention which is shown in Fig. 7, the sample 170 is conceptually subdivided into a

number of columns. After the sample 170 is subdivided, the pulsed laser beam 149 can be turned on (by actuating the excimer laser using the computer 100 or by opening the shutter 130) so that it produces the pulsed beamlets 164 which initially impinge on the first location 20 (similarly to the embodiment illustrated in Fig. 1b). Then, the sample 170 is translated and accelerated in the Y-direction under the control of the computer 100 to reach the predetermined sample translation velocity Vpred with respect to the pulsed beamlets 164 in a first beam path 700. The pulsed beamlets 164 (and the beamlets) reach an upper edge 10' of the sample 170 when the velocity of the translation of the sample 170 with respect to the pulsed laser beam 149 reaches the predetermined velocity Vpred. Then, the sample 170 is continuously (i.e., without stopping) translated in the Y-direction at the predetermined velocity Vpred continuously and sequentially so that the pulsed beamlets 164 irradiate the sample 170 for an entire length of a second beam path 705. When the pulsed beamlets 164 reach the lower edge 10" of the sample 170, the translation of the sample 170 is slowed with respect to the pulsed beamlets 164 (in a third beam path 710) to reach a second location 715. It should be noted that after the pulsed beamlets 164 pass the lower edge 10" of the sample 170, the entire portion of the sample 170 along the second beam path 705 has undergone sequential full melting and solidification.

The sample 170, without microtranslating in the X-direction, is translated back in the opposite Y-direction toward the upper edge 10' of the sample 170. In particular, the sample 170 is accelerated in the negative Y-direction under the control of the computer 100 along a fourth beam path 720 to reach the predetermined sample translation velocity Vpred prior to reaching the lower edge 10" of the sample 170. Then, the sample 170 is continuously (i.e., without stopping) translated in the negative Y-direction at the predetermined velocity Vpred so that the pulsed beamlets 164 continuously and sequentially irradiate the sample 170 along the entire length of a fifth beam path 725 (along the path of the second beam path 705). When the pulsed beamlets 164 reach the upper edge 10' of the sample 170, the translation of the sample 170 is slowed with respect to the pulsed beamlets 164 (in a sixth beam path 730) until the beamlets 164 impinge on the first location 20. It should be noted that after the pulsed beamlets 164 pass the upper edge 10' of the sample 170, the entire portion of the sample

170 which was irradiated along the second beam path 705 has undergone sequential melting and solidification. Accordingly, when this pass is completed, the surface of the sample 170 corresponding to the fifth beam path 725 is partially melted and resolidified. In this manner, the resulting film surface may be further smoothed out. In addition, using this technique, the energy output of the pulsed laser beam 149 (and of the pulsed beamlets 164) may be decreased to effectively smooth out the surface of the film. Similarly to the technique of Fig. 1b, a grain boundary-controlled polycrystalline silicon thin film area 540 forms in the irradiated regions of the sample 170, a portion of which is shown in Fig. 5b. This grain boundary-controlled polycrystalline silicon thin film area 540 extends for the entire length of the second and fifth irradiated beam paths 705, 725. Again, it is not necessary to shut down the pulsed laser beam 149 after the pulsed beamlets 164 have crossed the lower edge 10" of the sample 170, and is no longer irradiates the sample 170.

Thereafter, the sample 170 is microtranslated for a predetermined distance (e.g., 3 micrometers) in the X-direction along a seventh beam path 735 until the pulse beamlets impinge on a third location 740, and is then again accelerated in the forward Y-direction (toward the lower edge 10" of the sample 170) under the control of the computer 100 to reach the predetermined velocity Vpred with respect to the pulsed beamlets 164 along an eighth beam path 745. The pulsed beamlets 164 reach an upper edge 10' of the sample 170 when the velocity of translation of the sample 170 with respect to the pulsed beamlets 164 reach the predetermined velocity Vpred. Then, the sample 170 is continuously (i.e., without stopping) translated in the forward Y-direction at the predetermined velocity Vpred so that the pulsed beamlets 164 continuously and sequentially irradiate the sample 170 for an entire length of a ninth beam path 750. When the pulsed beamlets 164 reach the lower edge 10" of the sample 170, the translation of the sample 170 is slowed with respect to the pulsed beamlets 164 (in a tenth beam path 760) until the pulsed beamlet 164 impinge on a fourth location 765. It should be noted that after the final pulsed laser beam 164 pass the lower edge 10" of the sample 170, the entire portion of the sample 170 which was irradiated along the ninth beam path 750 has undergone sequential full melting and resolidification.

Thereafter, without microtranslating, the direction of the translation of the sample 170 is again reversed (via beam paths 770, 775, 780), and these paths of the sample 170 are again each continuously and sequentially irradiated by continuously translating the sample 170 in the reverse Y-direction (which also extends along the ninth beam path 750) at the predetermined velocity Vpred. Accordingly, when this pass is completed, the surface of the sample 170 corresponding to the beam path 775 is partially melted and resolidified. The surface of these paths 745-780 is smoothed out as a result of the forward and reverse Y-direction translation and irradiation along the same beam path of the sample 170 (without microtranslation). The final product of such procedure is the creation of large-grained, grain boundary-controlled crystalized structure along the entire column (e.g., dimensioned 2cm by 40cm) of the sample 170, having a flat (or flatter) surface.

Then, the sample 170 is stepped to the next column (i.e., the second column 6) until the beamlets impinge on a fifth location 790 via another beam path 785, and the sample 170 is allowed to settle to damp out any vibrations of the sample 170 and stage 180 that may have occurred when the sample 170 was stepped where the pulsed beamlets 164 impinge on the fifth location 790. The procedure is repeated for all columns of the sample 170, similarly to the procedure described above and illustrated in Fig. 1b.

Referring next to Fig. 8, the steps executed by computer 100 to control the thin silicon film crystallization growth method implemented according of the procedure shown in Fig. 1b and/or Fig. 7 is described below. For example, various electronics of the system shown in Fig. 1a are initialized in step 1000 by the computer 100 to initiate the process. A thin amorphous silicon film sample on a substrate 170 is then loaded onto the sample translation stage 180 in step 1005. It should be noted that such loading may be either manual or robotically implemented under the control of the computer 100. Next, the sample translation stage 180 is moved into an initial position in step 1015, which may include an alignment with respect to reference features on the sample 170. The various optical components of the system are adjusted and focused in step 1020, if necessary. The laser is then stabilized in step 1025 to a desired energy level and pulse repetition rate, as needed to fully melt the amorphous silicon sample over the cross-sectional area of each pulsed beamlet incident on the sample in accordance with the particular processing to be

carried out. If necessary, the attenuation of the pulsed beamlets 164 is finely adjusted in step 1030.

Next, the shutter can be opened (or the computer activates to turn on the pulsed laser beam 149) in step 1035 to irradiate the sample 170 by the pulsed beamlets 164 and accordingly, to commence the continuous motion sequential lateral solidification method illustrated in Figs. 1b and 7. The sample is translated in the Y-direction continuously while a first beam path of the sample (e.g., the sample along the second beam path 30) is continuously and sequentially irradiated (step 1040). The sample 170 is translated in the Y-direction continuously at the predetermined velocity Vpred while a second beam path of the sample (e.g., the sample along the sixth beam path 55) is sequentially and continuously irradiated (step 1045). With respect to Fig. 1b, this can be seen by the continuous translation of the sample 170 along the second beam path 30 while the sample 170 is being continuously and sequentially irradiated, then slowing down along the third beam path 35, microtranslating the sample along the X-direction along the fourth beam path 45, waiting for the sample 170 to settle, accelerating along the fifth beam path 50, and then continuously translating the sample 170 along the sixth beam path 55 while the sample 170 is being continuously and sequentially irradiated. In this manner, an entire column of the sample 170 is sequentially irradiated. If some portion of the current column of the sample 170 is not irradiated, the computer 100 controls the sample 170 to continuously translate at the predetermined velocity Vpred in a particular direction so that another portion of the current column of the sample 170 which has not yet been irradiated, is irradiated (step 1055).

Then, if the crystallization of an area of the sample 170 has been completed, the sample is repositioned with respect to the pulsed beamlets 164 in steps 1065, 1066 (i.e., moved to the next column or row - the second column 6) and the crystallization process is repeated on the new path. If no further paths have been designated for crystallization, the laser is shut off in step 1070, the hardware is shut down in step 1075, and the process is completed in step 1080. Of course, if processing of additional samples is desired or if the present invention is utilized for batch processing, steps 1005, 1010, and 1035 - 1065 can be repeated on each sample. It is well understood by those having ordinary skill in the art that the sample may also be continuously

translated in the X-direction, and microtranslated in the Y-direction. Indeed, it is possible to continuously translate the sample 170 in any direction so long as the travel paths of the pulsed beamlets 164 are parallel, continuous and extend from one edge of the sample 170 to another edge of the sample 170.

The foregoing merely illustrates the principles of the present invention. Various modifications and alterations to the described embodiments will be apparent to those skilled in the art in view of the teachings herein. For example, the thin amorphous or polycrystalline silicon film sample 170 may be replaced by a sample having pre-patterned islands of such silicon film. In addition, while the exemplary embodiments above have been described for laser systems in which the laser beams are fixed and preferably not scannable, it should be recognized that the method and system according to the present invention can utilize a pulsed laser beam which can be deflected at a constant speed along a path of a fixed sample. It will thus be appreciated that those skilled in the art will be able to devise numerous systems and methods which, although not explicitly shown or described herein, embody the principles of the present invention, and are thus within the spirit and scope of the present invention.

CLAIMS

1. A method for processing a silicon thin film sample to produce a crystalline silicon thin film, the film sample having a first edge and a second edge, the method comprising the steps of:

(a) controlling a laser beam generator to emit a laser beam;

(b) masking portions of the laser beam to generate patterned beamlets, each of the patterned beamlets impinging on the film sample and having an intensity which is sufficient to melt the film sample;

(c) continuously scanning, at a first constant predetermined speed, the film sample so that impingement of the patterned beamlets moves along a first path on the film sample between the first edge and the second edge with the patterned beamlets; and

(d) continuously scanning, at a second constant predetermined speed, the film sample so that impingement of the patterned beamlets moves along a second path on the film sample between the first edge and the second edge with the patterned beamlets.

2. The method of claim 1,

wherein step (c) comprises:

continuously translating the film sample so that the patterned beamlets sequentially irradiate first successive portions of the film sample along the first path, wherein the first portions are melted while being irradiated, and

wherein step (d) comprises:

continuously translating the film sample so that the patterned beamlets sequentially irradiate second successive portions of the film sample along the second path, wherein the second portions are melted while being irradiated.

3. The method of claim 2,

wherein, after the film sample is translated along the first path to irradiate a next first successive portion of the film sample, the previously irradiated first portion is resolidified, and

wherein, after the film sample is translated along the second path to irradiate a next second successive portion of the film sample, the previously irradiated second portion is resolidified.

4. The method of claim 1,

wherein the first path is parallel to the second path,

wherein, in step (c), the film sample is continuously scanned in a first direction, and

wherein, in step (d), the film sample is continuously scanned in a second direction, the first direction being opposite to the second direction.

5. The method of claim 1, wherein the first edge is located on a side of the film sample which is opposite from a side of the film sample where the second edge is located.

6. The method of claim 2, further comprising the steps of:

(e) before step (d), positioning the film sample so that the patterned beamlets impinge on at a first location outside of boundaries of the film sample with respect to the film sample; and

(f) after step (e) and before step (d), microtranslating the film sample so that impingement of the patterned beamlet moves from the first location to a second location,

wherein step (d) is initiated when the patterned beamlets impinge on the second location.

7. The method of claim 6, further comprising the steps of:

(g) after step (d), translating the film sample so that the patterned beamlets impinge on a third location which is outside the boundaries of the film sample;

(h) after step (g), stepping the film sample so that impingement of the patterned beamlets moves from the third location to a fourth location, the fourth location being outside of the boundaries of the film sample; and

(i) after step (h), maintaining the film sample so that the patterned beamlets impinge on the fourth location until any vibration of the film sample is damped out.

8. The method of claim 7, further comprising the step of:

(j) after step (i), repeating steps (c) and (d) for respective third and fourth paths of the patterned beamlets on the film sample.

9. The method of claim 2,

wherein, in step (c), the film sample is continuously scanned in a first direction, and

wherein, in step (d), the film sample is continuously scanned in a second direction, and further comprising the steps of:

(k) after step (c), continuously translating at the first constant predetermined speed the film sample so that impingement of the patterned beamlets moves along the first path to reach a first location, wherein the patterned beamlets irradiate the first successive portions of the film sample, the film sample being translated in a direction which is opposite to the first direction;

(l) after step (k) and before step (d), microtranslating the film sample so that impingement of the patterned beamlets moves from the first location to a second location, the second location being outside of boundaries of the film sample; and

(m) after steps (l) and (d), continuously translating at the second constant

predetermined speed the film sample so that impingement of the patterned beamlets moves along the second path to reach the second location, wherein the patterned beamlets irradiate the second successive portions of the film sample, the film sample being translated in a direction which is opposite to the second direction.

10. The method of claim 9, further comprising the steps of:

(n) after step (m), stepping the film sample so that impingement of the patterned beamlets moves from outside the boundaries of the film sample from the second location to a third location; and

(o) maintaining the film sample so that the patterned beamlets impinge on the third location until any vibration of the film sample is damped out.

11. The method of claim 10, further comprising the step of:

(p) after step (p), repeating steps (c), (d), (k), (l) and (m) so that impingement of the patterned beamlets moves along respective third and fourth paths on the film sample.

12. A system for processing a polycrystalline silicon thin film sample into a crystalline thin film, the film sample having a first edge and a second edge, the system comprising:

a memory storing a computer program; and

a processing arrangement executing the computer program to perform the following steps:

(a) controlling a laser beam generator to emit a laser beam,

(b) masking portions of the laser beam to generate patterned beamlets, each of the patterned beamlets impinging on the film sample having an intensity which is sufficient to melt the film sample,

(c) continuously scanning, at a first constant predetermined speed, the film sample so that impingement of the patterned beamlets moves

along a first path on the film sample between the first edge and the second edge with the patterned beamlets, and

(d) continuously scanning, at a second constant predetermined speed, the film sample so that impingement of the patterned beamlets moves along a second path on the film sample between the first edge and the second edge with the patterned beamlets.

13. The system of claim 12,

wherein, during the execution of step (c), the processing arrangement continuously translates the film sample so that impingement of the patterned beamlets moves along the first path, wherein the patterned beamlets irradiate successive first portions of the film sample, the first portions being melted while being irradiated, and

wherein, during the execution of step (d), the processing arrangement continuously translates the film sample so that impingement of the patterned beamlets moves along the second path, wherein the patterned beamlets irradiate successive second portions of the film sample, the second portions being melted while being irradiated.

14. The system of claim 13,

wherein, after the processing arrangement causes the translation of the film sample so that the patterned beamlets irradiate a next first successive portion along the first path of the film sample, the previously irradiated first portion along the first path is resolidified, and

wherein, after the processing arrangement causes the translation of the film sample so that the patterned beamlets irradiate a next successive second portion along the second path of the film sample, the previously irradiated second portion along the second path is resolidified.

15. The system of claim 12,

wherein the first path is parallel to the second path,

wherein, while executing step (c), the processing arrangement causes the film sample to be continuously scanned in a first direction, and

wherein, while executing step (d), the processing arrangement causes the film sample to be continuously scanned in a second direction, the first direction being opposite to the second direction.

16. The system of claim 12, wherein the first edge is located on a side of the film sample which is opposite from a side of the film sample at which the second edge is located.

17. The system of claim 13,

wherein the processing arrangement executes the following additional steps:

(e) before step (d), positioning the film sample so that the patterned beamlets impinge on a first location outside of boundaries of the film sample with respect to the film sample, and

(f) after step (e) and before step (d), microtranslating the film sample so that impingement of the patterned beamlets moves from the first location to a second location, and

wherein the processing arrangement executes step (d) with the patterned beamlets initially impinging on the second location.

18. The system of claim 17, wherein the processing arrangement executes the following additional steps:

(g) after step (d), translating the film sample so that impingement of the patterned beamlets moves to a third location which is outside the boundaries of the film sample,

(h) after step (g), stepping the film sample so that impingement of the patterned beamlets moves from the third location to a fourth location, the fourth location being outside of the boundaries of the film sample, and

(i) after step (h), maintaining the film sample so that the patterned

beamlets impinge on the fourth location until any vibration of the film sample is damped out.

19. The system of claim 18, wherein the processing arrangement executes the following additional step:

(j) after step (i), repeating steps (c) and (d) for impingement of the patterned beamlets along respective third and fourth paths on the film sample.

20. The system of claim 13,

wherein, while executing step (c), the processing arrangement continuously translates the film sample in a first direction,

wherein, while executing step (d), the processing arrangement continuously translates the film sample in a second direction, and

wherein the processing arrangement executes the following additional steps:

(k) after step (c), continuously translating at the first constant predetermined speed the film sample so that impingement of the patterned beamlets moves along the first path to reach a first location, wherein the patterned beamlets sequentially irradiate the first successive portions of the film sample, the film sample being translated in a direction which is opposite to the first direction,

(l) after step (k) and before step (d), microtranslating the film sample so that impingement of the patterned beamlets moves from the first location to a second location, the second location being provided outside of boundaries of the film sample, and

(m) after steps (l) and (d), continuously translating at the second constant predetermined speed the film sample so that impingement of the patterned beamlets moves along the second path to reach the second location so that the patterned beamlets sequentially irradiate the second successive portions of the film sample, the film sample being translated in a direction which is

opposite to the second direction.

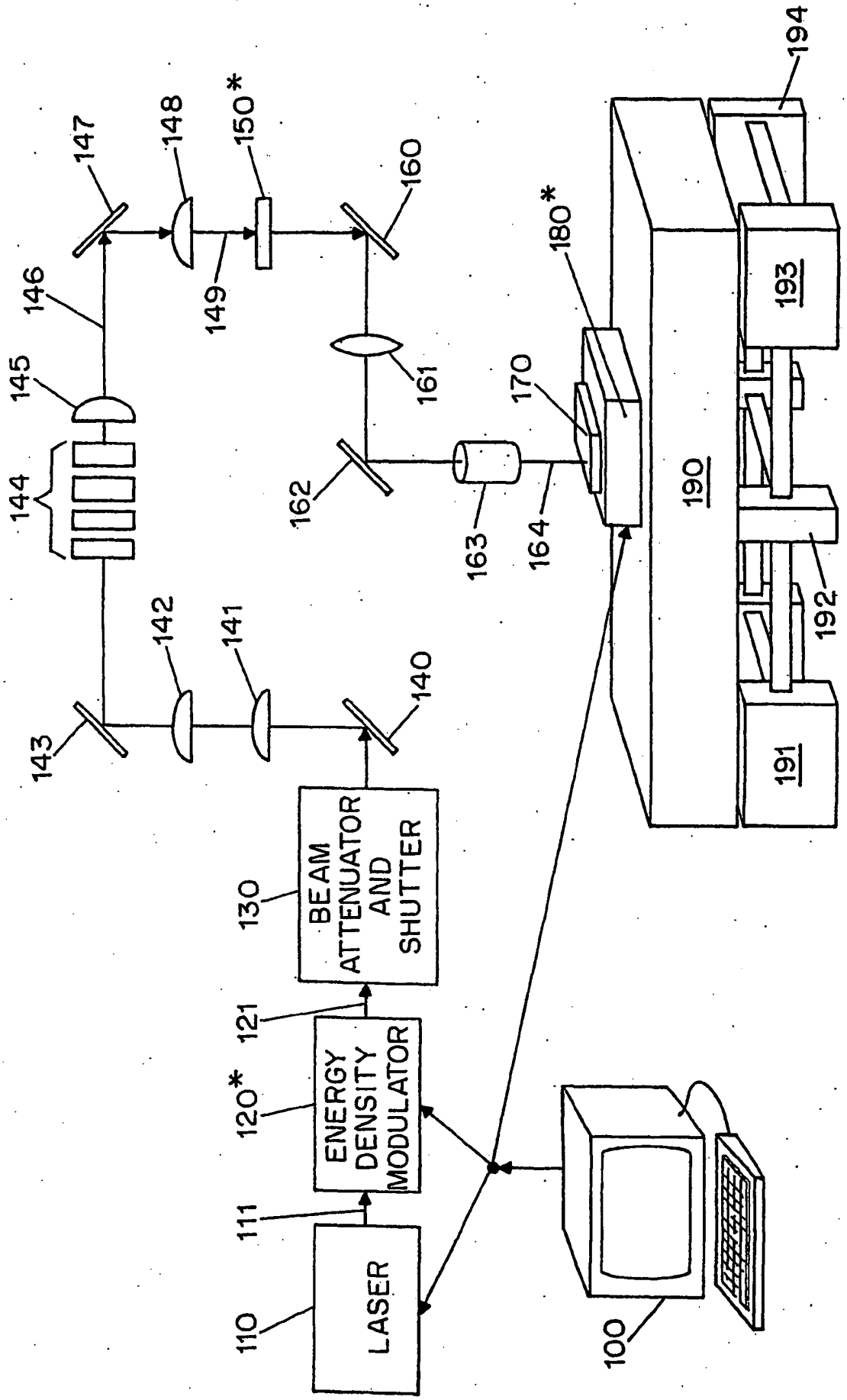
21. The system of claim 20, wherein the processing arrangement executes the following additional steps:

(n) after step (m), stepping the film sample so that impingement of the patterned beamlets moves from outside the boundaries of the film sample from the second location to a third location, and

(o) maintaining the film sample so that the patterned beamlets impinge on the third location until any vibrating of the film sample is damped out.

22. The system of claim 21, wherein the processing arrangement executes the following additional step:

(p) after step (p), repeating steps (c), (d), (k), (l) and (m) for moving the impingement of the patterned beamlets along respective third and fourth paths on the film sample.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142
141
140
143
BEAM ATTENUATOR AND SHUTTER
130
121
ENERGY DENSITY MODULATOR
120*
111
LASER
110
100

FIG. 1A

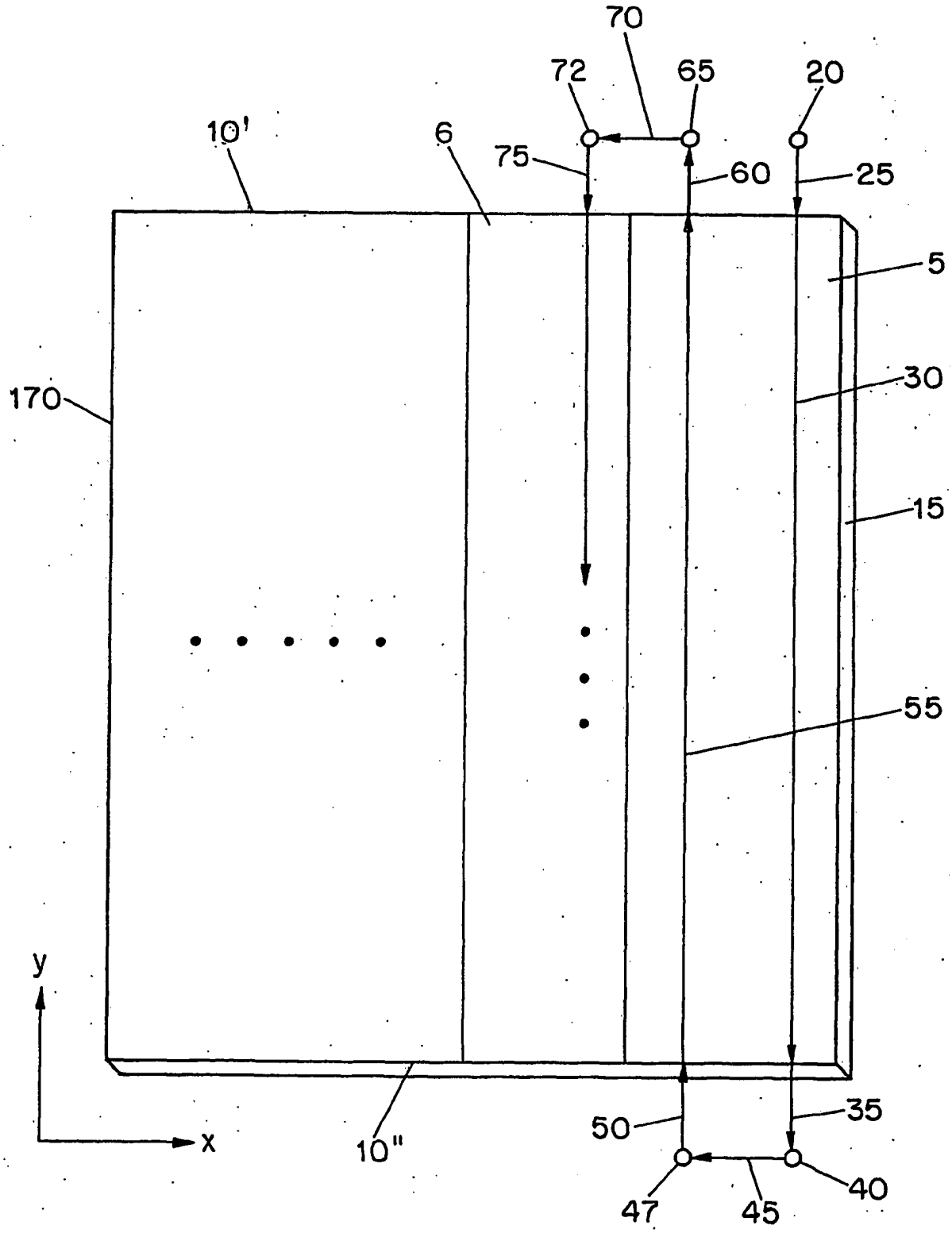


FIG. 1B

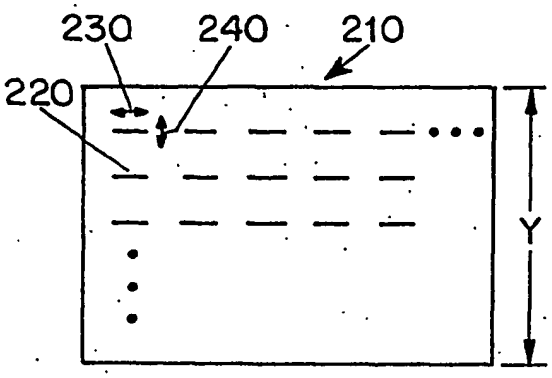


FIG. 2A

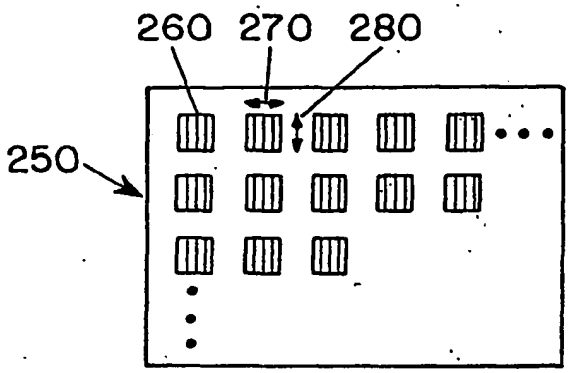


FIG. 2B

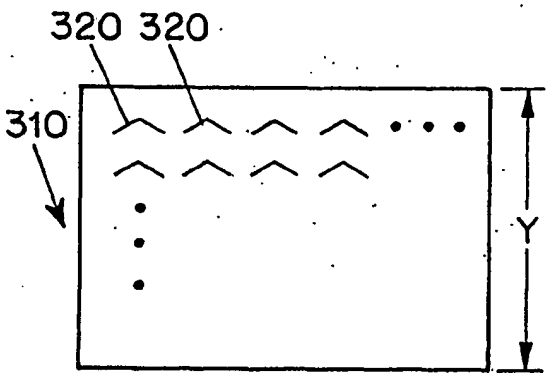


FIG. 3A

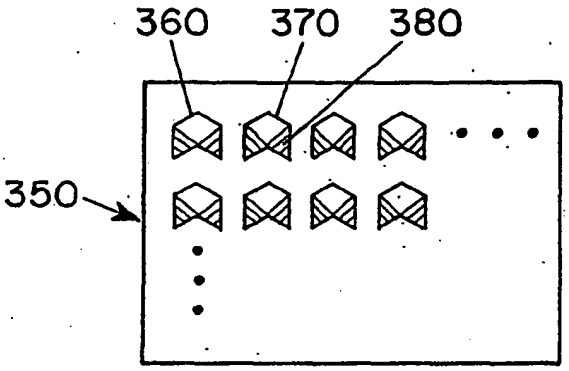


FIG. 3B

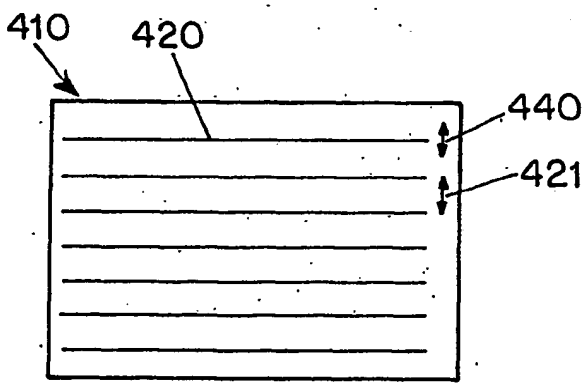


FIG. 4A

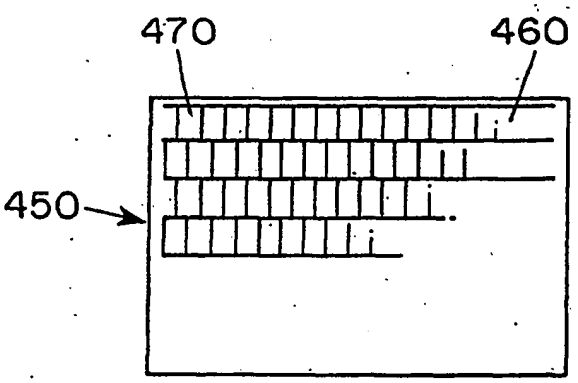


FIG. 4B

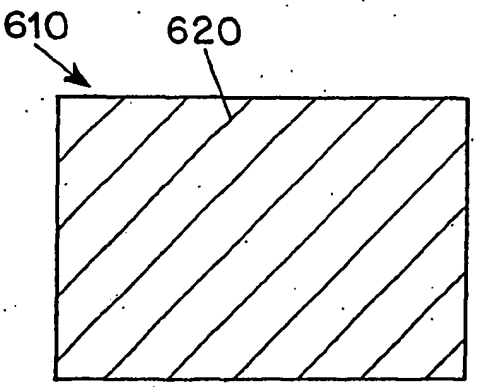


FIG. 6A

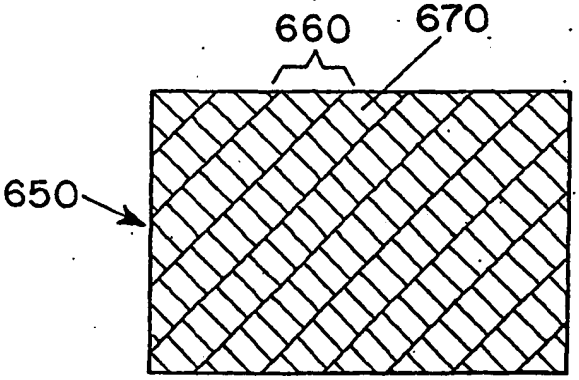


FIG. 6B

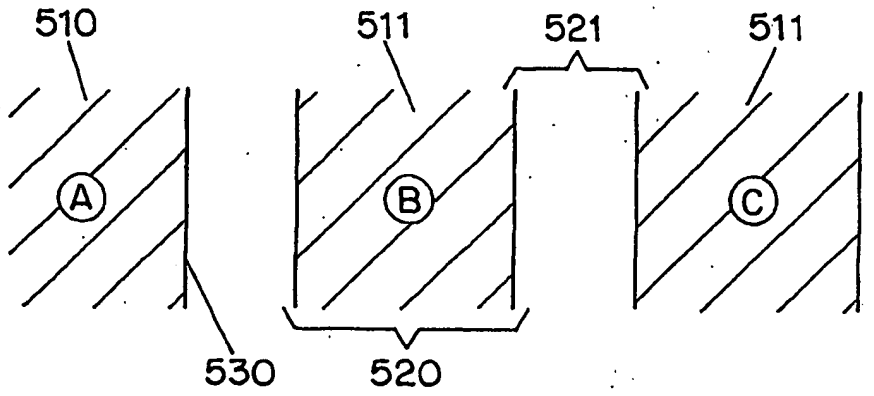


FIG. 5A

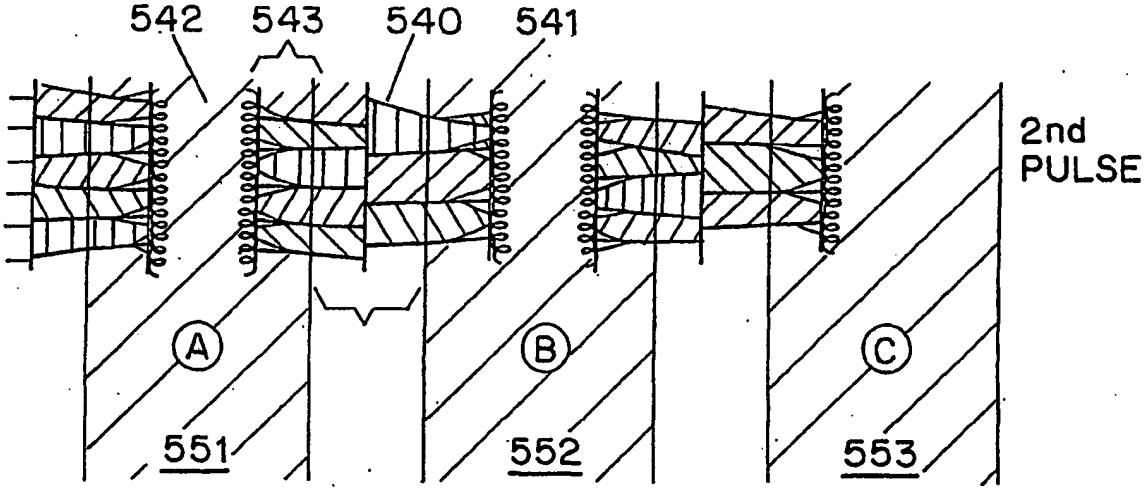


FIG. 5B

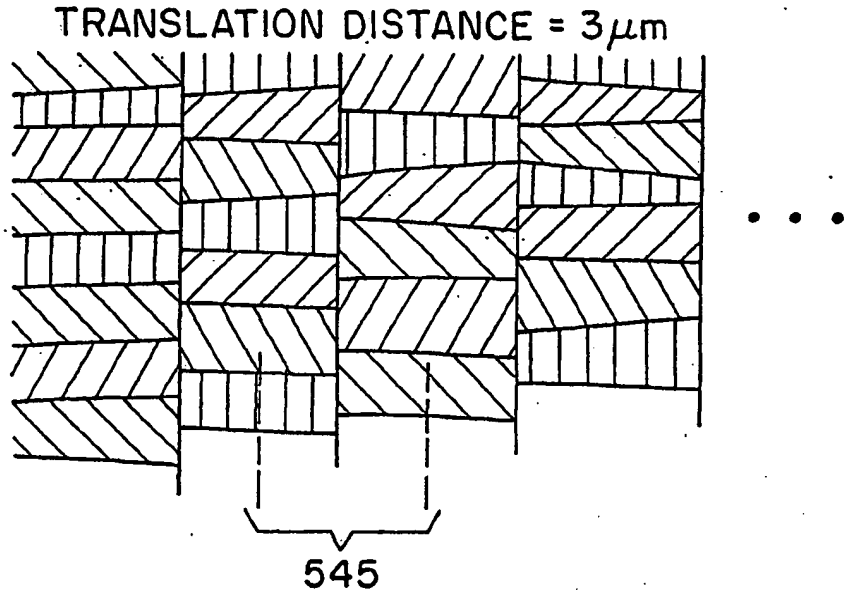
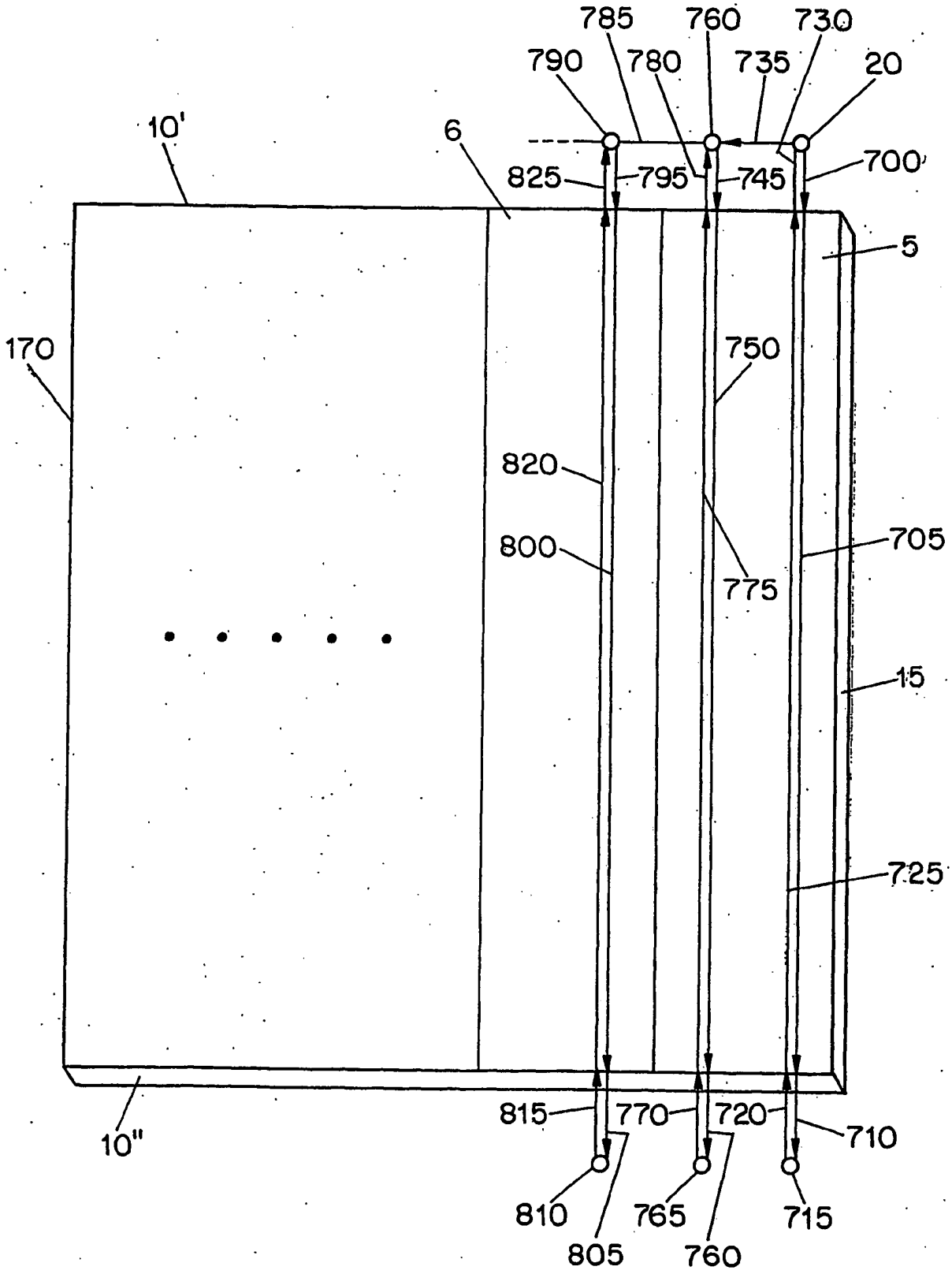


FIG. 5C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760
730
790
780
735
20
10'
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825
795
745
700
5
170
750
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705
775
15
725
10"
815
770
720
710
810
765
715
805
760

FIG. 7

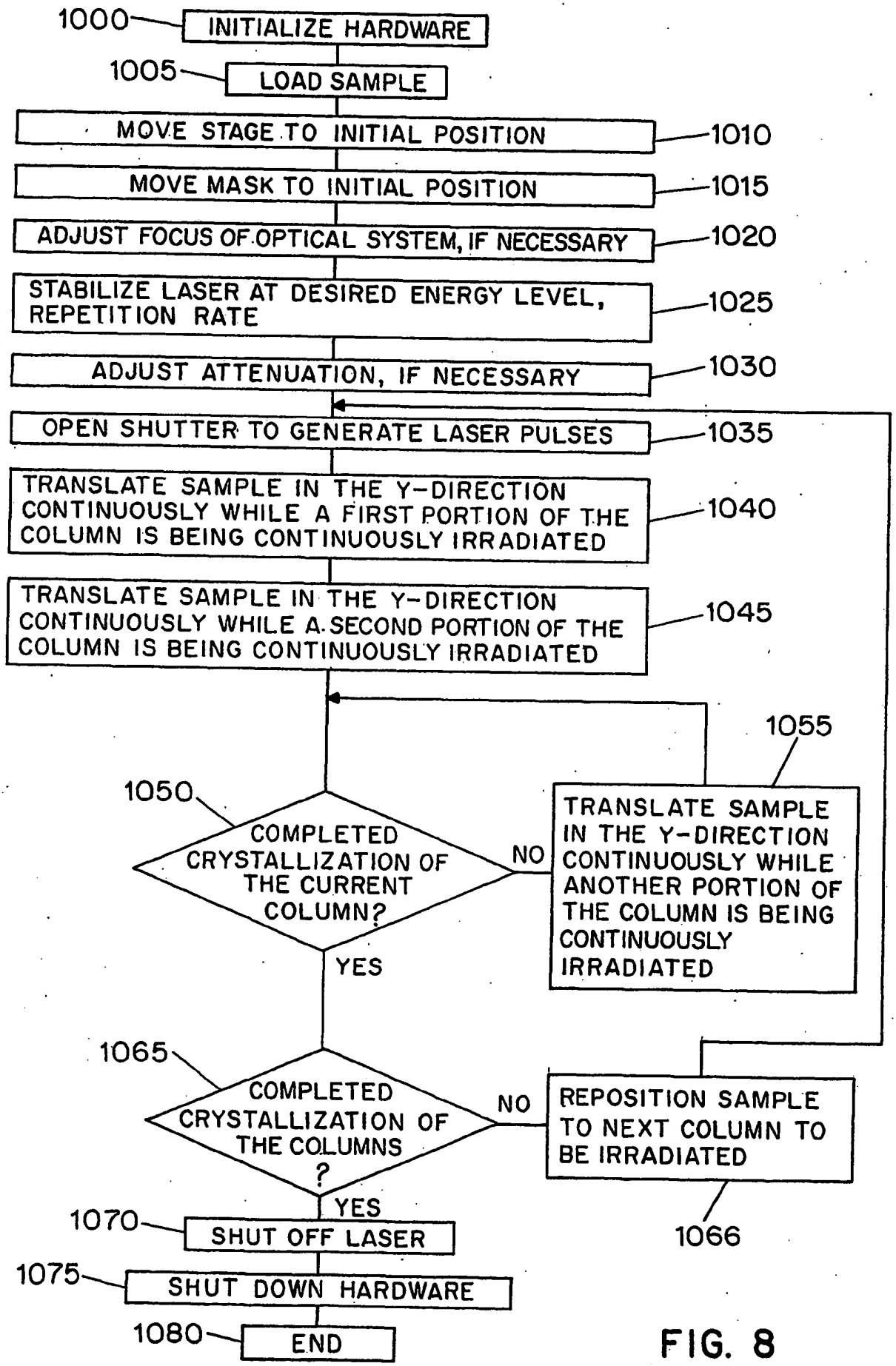
1000
INITIALIZE HARDWARE
1005
LOAD SAMPLE
MOVE STAGE TO INITIAL POSITION
1010
MOVE MASK TO INITIAL POSITION
1015
ADJUST FOCUS OF OPTICAL SYSTEM, IF NECESSARY
1020
STABILIZE LASER AT DESIRED ENERGY LEVEL, REPETITION RATE
1025
ADJUST ATTENUATION, IF NECESSARY
1030
OPEN SHUTTER TO GENERATE LASER PULSES
1035
TRANSLATE SAMPLE IN THE Y-DIRECTION CONTINUOUSLY WHILE A FIRST PORTION OF THE COLUMN IS BEING CONTINUOUSLY IRRADIATED
1040
TRANSLATE SAMPLE IN THE Y-DIRECTION CONTINUOUSLY WHILE A SECOND PORTION OF THE COLUMN IS BEING CONTINUOUSLY IRRADIATED
1045
1055
1050
COMPLETED CRYSTALLIZATION OF THE CURRENT COLUMN?
NO
TRANSLATE SAMPLE IN THE Y-DIRECTION CONTINUOUSLY WHILE ANOTHER PORTION OF THE COLUMN IS BEING CONTINUOUSLY IRRADIATED
YES
1065
COMPLETED CRYSTALLIZATION OF THE COLUMNS ?
NO
REPOSITION SAMPLE TO NEXT COLUMN TO BE IRRADIATED
1066
YES
1070
SHUT OFF LASER
1075
SHUT DOWN HARDWARE
1080
END

FIG. 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/07724

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/268

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A X	US 5 893 990 A (TANAKA KOICHIRO) 13 April 1999 (1999-04-13) figure 12	1-11 12-22
A	US 5 145 808 A (SAMESHIMA TOSHIYUKI ET AL) 8 September 1992 (1992-09-08) column 2, line 3 - line 58; figure 1	1-11
A	EP 0 681 316 A (SONY CORP) 8 November 1995 (1995-11-08) figure 2	1-22

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 August 2001	06/09/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Le Meur, M-A

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US 01/07724

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		US 5888839 A	30-03-1999

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(19) World Intellectual Property Organization
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(10) International Publication Number
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60/239,194 10 October 2000 (10.10.2000) US

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(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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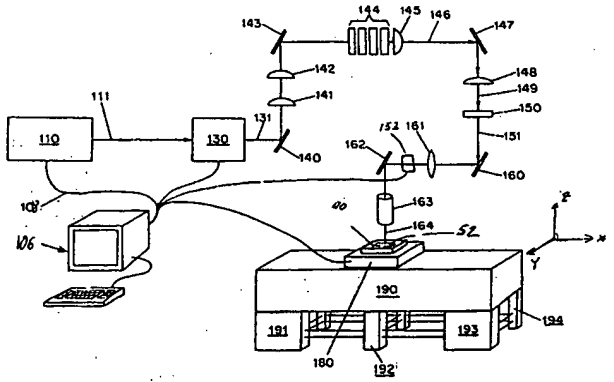
[Continued on next page]

(54) Title: METHOD AND APPARATUS FOR PROCESSING THIN METAL LAYERS



(57) Abstract: A method and apparatus for processing a thin metal layer on a substrate to control the grain size, grain shape, and grain boundary location and orientation in the metal layer by irradiating the metal layer with a first excimer laser pulse having an intensity pattern defined by a mask to have shadow regions and beamlets. Each region of the metal layer overlapped by a beamlet is melted throughout its entire thickness, and each region of the metal layer overlapped by a shadow region remains at least partially unmelted. Each at least partially unmelted region adjoins adjacent melted regions. After irradiation by the first excimer laser pulse, the melted regions of the metal layer are permitted to resolidify. During resolidification, the at least partially unmelted regions seed growth of grains in adjoining melted regions to produce larger grains. After completion of resolidification of the melted regions following irradiation by the first excimer laser pulse, the metal layer is irradiated by a second excimer laser pulse having a shifted intensity pattern so that the shadow regions overlap regions of the metal layer having fewer and larger grains. Each region of the metal layer overlapped by one of the shifted beamlets is melted throughout its entire thickness, while each region of the metal layer overlapped by one of the shifted shadow regions remains at least partially unmelted. During resolidification of the melted regions after irradiation by the second radiation beam pulse, the larger grains in the at least partially unmelted regions seed growth of even larger grains in adjoining melted regions. The irradiation, resolidification and re-irradiation of the metal layer may be repeated, as needed, until a desired grain structure is obtained in the metal layer.

WO 02/031869 A3

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/31391

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/768

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, INSPEC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	HAU-RIEGE C S ET AL: "The effects of microstructural transitions at width transitions on interconnect reliability" JOURNAL OF APPLIED PHYSICS, 15 JUNE 2000, AIP, USA, vol. 87, no. 12, pages 8467-8472, XP002200743 ISSN: 0021-8979 the whole document --- -/--	1

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
31 May 2002	14/06/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Königstein, C

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/31391

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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X	SPOSILI R S ET AL: "SEQUENTIAL LATERAL SOLIDIFICATION OF THIN SILICON FILMS ON SIO2" APPLIED PHYSICS LETTERS, AMERICAN INSTITUTE OF PHYSICS. NEW YORK, US, vol. 69, no. 19, 4 November 1996 (1996-11-04), pages 2864-2866, XP000955150 ISSN: 0003-6951 figure 1	68-71
X	MCWILLIAMS B M ET AL: "WAFER-SCALE LASER PANTOGRAPHY: FABRICATION OF N-METAL-OXIDE-SEMICONDUCTOR TRANSISTORS AND SMALL-SCALE INTEGRATED CIRCUITS BY DIRECT-WRITE LASER-INDUCED PYROLYTIC REACTIONS" APPLIED PHYSICS LETTERS, AMERICAN INSTITUTE OF PHYSICS. NEW YORK, US, vol. 43, no. 10, November 1983 (1983-11), pages 946-948, XP000816966 ISSN: 0003-6951 figure 1	68
X	MARIUCCI L ET AL: "Grain boundary location control by patterned metal film in excimer laser crystallized polysilicon" PROCEEDINGS OF THE FIFTH INTERNATIONAL CONFERENCE ON POLYCRYSTALLINE SEMICONDUCTORS (POLYSE '98), SCHWABISCH GMUND, GERMANY, 13-18 SEPT. 1998, vol. 67-68, pages 175-180, XP008004041 Diffusion and Defect Data Part B (Solid State Phenomena), 1999, Balaban Publishers;Scitec Publications, Switzerland ISSN: 1012-0394 the whole document	1
A	BROADBENT E K ET AL: "Excimer laser processing of Al-1%Cu/TiW interconnect layers" 1989 PROCEEDINGS. SIXTH INTERNATIONAL IEEE VLSI MULTILEVEL INTERCONNECTION CONFERENCE (CAT. NO.89TH0259-2), SANTA CLARA, CA, USA, 12-13 JUNE 1989, pages 336-345, XP010092413 1989, New York, NY, USA, IEEE, USA the whole document	1,20,31, 32,39, 49,67
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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/31391

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 591 668 A (MAEGAWA SHIGEKI ET AL) 7 January 1997 (1997-01-07) figures 1A,1B	

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 01/31391

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		KR 153834 B1	01-12-1998

⑲日本国特許庁(JP)　⑪特許出願公開

⑫公開特許公報(A)　昭62-181419

⑤1Int.Cl.⁴	識別記号	庁内整理番号	④3公開　昭和62年(1987)8月8日
H 01 L 21/20		7739-5F	
C 30 B 1/02		8518-4G	
29/06		8518-4G	
H 01 L 21/263		7738-5F	
29/78		8422-5F	審査請求　未請求　発明の数 1　(全4頁)

⑤4発明の名称　多結晶シリコンの再結晶化法

⑳特　願　昭61-24410
㉒出　願　昭61(1986)2月5日

⑦2発明者　若海　弘夫　東京都港区芝5丁目33番1号　日本電気株式会社内
⑦1出願人　日本電気株式会社　東京都港区芝5丁目33番1号
⑦4代理人　弁理士　内原　晋

明　細　書

発明の名称

多結晶シリコンの再結晶化法

特許請求の範囲

ガラス基板上に第1の絶縁膜と高熱伝導層を積層し、さらに該高熱伝導層上に第2の絶縁膜と多結晶シリコン層と該多結晶シリコン層を覆う第3の絶縁膜からなるキャップ層とを島状に連続して積み重ね、前記キャップ層上から高エネルギービームを照射して前記多結晶シリコン層の結晶粒度を大きくすることを特徴とする多結晶シリコンの再結晶化法。

発明の詳細な説明

〔産業上の利用分野〕

本発明は、平面表示装置の駆動用トランジスタを構成する基本要素である薄膜の多結晶シリコンの再結晶化方法に関する。

〔従来の技術〕

近年，ＥＬＤ，ＬＣＤ等の表示装置が大容量化するにつれて、各セルをＴＦＴで駆動するアクティブマトリックス駆動方式が検討されるようになってきた。この方式では、各セル毎に設けたＴＦＴの他に、Ｘ，Ｙの電極線を駆動するためのドライバが必要であるが、これらはＴＦＴと共にガラス基板の上にＩＣ化されるのが価格的に望ましい。このドライバとしては相互コンダクタンスｇｍが大きく、高速に動作する程、表示装置の性能が向上し、大容量化が可能になる。

通常よく用いられる低圧ＣＶＤ法で成膜された多結晶シリコンの移動度は非常に低く、数cm^2／V・sec程度であり、単結晶シリコンと比べて2桁も小さい。この原因としては、ダングリングボンドが多く、結晶の粒界に多くのトラップ準位を持つために、この電気的に活性なトラップにキャリアが捕えられ、周辺領域を空乏化し、電位障壁が形成されるからと考えられている。

このような問題を改善するために、水素イオンでダングリングボンドをターミネイトすることにより電位障壁を無くす水素プラズマ処理法も検討されているが、高々１０cm^2／v・sec程度の移動度しか得られていない。

これに対し、多結晶シリコン薄膜に電子ビームやレーザビームを照射することにより溶融再結晶化して、結晶粒度の大きい膜を得る方法も検討されている。

次に、第２図を用いて、従来の多結晶シリコンの再結晶化法の第１の例を説明する。

ガラス基板１１上に島状に設けた多結晶シリコン層１５をSiO_2やSi_3N_4等の絶縁膜からなるキャップ層１６でおおい、その上からｃｗＡｒレーザやパルスモードのＹＡＧレーザでスポット状のビームを走査照射する。この場合、キャップ層１６は溶融したシリコンが蒸発するのを防止するために設けられているものである。

高エネルギーのビームを照射すると、多結晶シリコンが溶融するため、ガラス基板１１との界面付近の温度はシリコンの溶融点（～１４００℃）近くになる。このためガラス基板１１としては石英ガラスの如き高融点のガラスに制限される。また石英ガラスは熱電動率が低いので、多結晶シリコン層１５の結晶粒子の成長に不適当な熱分布（エッジ部より中央部の温度が高い）ができ、結晶性の良い膜が形成されにくい。

第３図は、従来の多結晶シリコン再結晶化法の第２の例を説明する為の図である。

この第２の例は、第１の例よりも簡便な手法であり、石英基板１１上の多結晶シリコン層１５に直接ビームを照射して溶融再結晶化する方法を用いている。この場合も、ガラス基板１１の界面付近の温度は第１の例と同じように高温に達するので、ガラス基板１１としては石英ガラスに制限される。

〔発明が解決しようとする問題点〕

ところで、これらのガラス基板上に形成されたドライバをＥＬＤやＬＣＤ等の表示装置と一体化すると、表示装置の価格は高くなる。特に、表示面積が大きくなる程、基板の価格が大きな割合を占めるようになる。従来の方法では、高温処理に伴う熱亜により安価なホウケイ酸ガラスを使用することは不可能なので、表示装置の価格が高くならざるを得なかった。また、島状に設けた多結晶シリコンを再結晶化する際の温度分布が結晶粒子の成長には不適当になるため（中央部が高温）、結晶性の良い膜を容易に形成し難かった。

本発明の目的は、かかる従来の欠点を除き、低熱伝導度の絶縁膜と高熱伝導度のヒートシンク層を設けて、高効率で基板への熱的影響の少い多結晶シリコンの再結晶化法を提供することにある。

〔問題点を解決するための手段〕

本発明の多結晶シリコンの再結晶化法は、ガラス基板上に第１の絶縁膜と高熱伝導層を積層し、さらに該高熱伝導層上に第２の絶縁膜と多結晶シリコン層と該多結晶シリコン層を覆う第３の絶縁層からなるキャップ層とを島状に連続して積み重ね、前記キャップ層上から高エネルギービームを照射して前記多結晶シリコン層の結晶粒度を大きくするものである。

〔発明の原理と作用〕

ガラス基板上に適当な膜厚のSiO_2の如き絶縁膜とＷの如き高融点金属からなる高熱伝導層とをつけ、更にその上に島状にＡｌＮの如き高熱伝導絶縁膜と多結晶シリコンを成長し、Si_3N_4のような絶縁膜からなるキャップ層でこれら高熱伝導絶縁膜と多結晶シリコン層をおおう。この上から、ｃｗＡｒレーザやパルスモードのＹＡＧレーザーを用いてビームを照射すると、多結晶シリコンは溶融再結晶化されるかあるいはアニーリングされて、多結晶シリコン層の結晶粒度は大きくなる。

この場合、多結晶シリコン層の下に、熱伝導度の高い絶縁膜及び高融点金属を設けてあるので、熱はこの高熱伝導絶縁膜を通して金属膜へと伝導し、熱伝導率の著しく小さいSiO_2膜で阻止され、島状の多結晶シリコン層の領域外に延びて設けられている高融点金属膜からほとんどの熱が外部へ放散されることになる。

従って、多結晶シリコン層に高エネルギービームを照射している時の多結晶シリコン層の温度は融点近傍になるとも、SiO_2膜下のガラス基板表面の温度はSiO_2の膜厚を適当に選べば十分低く設定できることになり、熱歪点が約７００℃のホウケイ酸ガラスを基板として用いることができるようになる。また、ヒートシンクである高熱伝導層を設けたことにより、多結晶シリコン層の端部が中央部より高温となるため、エッジヒーティング効果によりビーム照射後に得られる多結晶シリコンの結晶性は良くなる。

〔実施例〕

以下、本発明の実施例について図面を参照し乍ら詳細に説明する。

第１図は本発明の一実施例となる多結晶シリコンの再結晶化法を説明する為の図である。

まずガラス基板１１上にSiO_2の如き低熱伝導度を持つ第１の絶縁膜１２とＷやＭｏの如き高融点金属からなる高熱伝導層１３を形成する。高熱伝導層１３としては、必ずしも高融点金属のみにこだわるわけではなく、他の高熱伝導度を有する不純物を導入した多結晶シリコン等のような膜であってもよい。

このような高熱伝導度を持つ高熱伝導層１３の上に、ＡℓＮ等の高熱伝導度を有する絶縁膜１４と多結晶シリコン層１５を島状に形成する。尚、絶縁膜１４は、多結晶シリコン層１５を加熱した時に高熱伝導層１３と多結晶シリコン層１５との化学的反応が生じ、多結晶シリコン層中に不純物が混入して膜質が部分的に劣化するのを防止するために設けている。絶縁膜１４としては熱をよく伝導する薄い膜厚からなるSiO_2であってもよい。

次に、多結晶シリコン層１５と絶縁膜１４とをSiO_2やSi_3N_4あるいはこれらの多層膜からなるキャップ層１６でおおい、その上からｃｗＡｒレーザーやパルスモードのＹＡＧレーザーのビームを照射する。すると、多結晶シリコン層１５は溶融するかアニーリングされる。この時、加えられた熱エネルギーは、絶縁膜１４と高熱伝導層１３とを通り、島状領域から外部に延伸された高熱伝導層１３を介して外部へ放散される。

一方、ヒートシンク材としての高熱伝導層１３の下に設けてある絶縁膜１２の熱伝導度は、例えばSiO_2の場合はSiに比べても３桁以上も小さいので、下のガラス基板１１への熱伝導は大部分阻止される。従って、熱伝導を阻止する絶縁膜１２の膜厚を適切に選べば、ガラス基板１１としては高価な石英でなく、安価なホウケイ酸ガラスを使うこともできる。また、島状の多結晶シリコン層１５の端部の温度は、ヒートシンクにより中央部より低くなるので、いわゆるエッジヒーティング効果により高品質の再結晶化膜が得られる。

〔発明の効果〕

以上説明したように本発明によれば、基板に対する発熱効果を小さくすることができるので、低温歪点を有するホウケイ酸ガラス基板上にも多結晶シリコンの再結晶層を形成できる効果がある。

この結果、平面表示装置の駆動用のＴＦＴの基板コストは、石英等の高価なガラス基板を用いる必要がないので、安価になる。

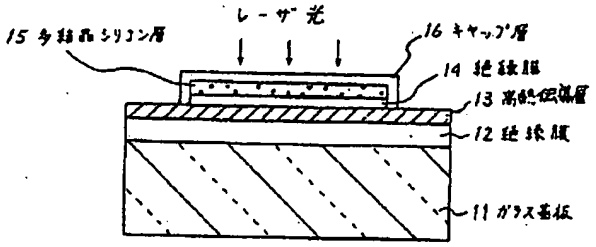
また、多結晶シリコン層の下にヒートシンク用の高熱伝導層を設けて、熱が中心から周辺へ伝導し、外部へ放散するようにしているので、エッジヒーティング効果がうまく作用し、結晶性の良い膜が効率よく得られる。この効果は、基板として石英基板を用いた場合でももちろん得られる。

図面の簡単な説明

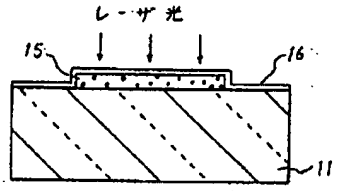
第１図は本発明の第一の実施例を説明する為の図、第２図及び第３図は従来の多結晶Siの再結晶化法を説明する為の図である。

１１…ガラス基板、１２…絶縁膜、１３…高熱伝導層、１４…絶縁膜、１５…多結晶シリコン層、１６…キャップ層。

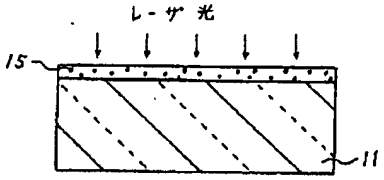
代理人　弁理士　内　原　晋


レーザ光
15 多結晶シリコン層
16 キャップ層
14 絶縁膜
13 高熱伝導層
12 絶縁膜
11 ガラス基板

第1図


レーザ光
15
16
11

第2図


レーザ光
15
11

第3図

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(54) Title: METHODS FOR PRODUCING UNIFORM LARGE-GRAINED AND GRAIN BOUNDARY LOCATION MANIPULATED POLYCRYSTALLINE THIN FILM SEMICONDUCTORS USING SEQUENTIAL LATERAL SOLIDIFICATION

(57) Abstract: Methods for processing an amorphous silicon (542) thin film sample (170) into a polycrystalline silicon (540) thin film are disclosed. In one preferred arrangement, a method includes the steps of generating a sequence of excimer laser pulses (164), controllably modulating each excimer laser (110) pulse in the sequence to a predetermined fluency, homogenizing each modulated laser pulse in the sequence in a predetermined plane, masking portions of each homogenized fluency controlled laser pulse in the sequence with a two dimensional pattern of slits (220) to generate a sequence of fluency controlled pulses of line patterned beamlets, each slit in the pattern of slits being sufficiently narrow to prevent inducement of significant nucleation in region of a silicon thin film sample irradiated by a beamlet corresponding to the slit, irradiating an amorphous silicon thin film sample with the sequence of fluency controlled slit patterned beamlets to effect melting of portions thereof corresponding to each fluency controlled patterned

METHODS FOR PRODUCING UNIFORM LARGE-GRAINED AND GRAIN BOUNDARY LOCATION MANIPULATED POLYCRYSTALLINE THIN FILM SEMICONDUCTORS USING SEQUENTIAL LATERAL SOLIDIFICATION

SPECIFICATION

BACKGROUND OF THE INVENTION

I. Field of the invention.

The present invention relates to techniques for semiconductor processing, and more particularly to semiconductor processing which may be performed at low temperatures.

II. Description of the related art.

In the field of semiconductor processing, there have been several attempts to use lasers to convert thin amorphous silicon films into polycrystalline films. For example, in James Im et al., "Crystalline Si Films for Integrated Active-Matrix Liquid-Crystal Displays," 11 MRS Bullitin 39 (1996), an overview of conventional excimer laser annealing technology is presented. In such a system, an excimer laser beam is shaped into a long beam which is typically up to 30 cm long and 500 micrometers or greater in width. The shaped beam is scanned over a sample of amorphous silicon to facilitate melting thereof and the formation of polycrystalline silicon upon resolidification of the sample.

The use of conventional excimer laser annealing technology to generate polycrystalline silicon is problematic for several reasons. First, the polycrystalline silicon generated in the process is typically small grained, of a random microstructure, and having a nonuniform grain sizes, therefore resulting in poor and nonuniform devices and accordingly, low manufacturing yield. Second, in order to obtain acceptable performance levels, the manufacturing throughput for producing polycrystalline silicon must be kept low. Also, the process generally requires a controlled atmosphere and preheating of the amorphous silicon sample, which leads to a reduction in throughput

rates. Accordingly, there exists a need in the field to generate higher quality polycrystalline silicon at greater throughput rates. There likewise exists a need for manufacturing techniques which generate larger and more uniformly microstructured polycrystalline silicon thin films to be used in the fabrication of higher quality devices, such as flat panel displays.

SUMMARY OF THE INVENTION

An object of the present invention is to provide techniques for producing uniform large-grained and grain boundary location controlled polycrystalline thin film semiconductors using the sequential lateral solidification process.

A further object of the present invention is to form large-grained and grain boundary location manipulated polycrystalline silicon over substantially the entire semiconductor sample.

Yet another object of the present invention is to provide techniques for the fabrication of semiconductors devices useful for fabricating displays and other products where the predominant orientation of the semiconductor grain boundaries may be controllably aligned or misaligned with respect to the current flow direction of the device.

In order to achieve these objectives as well as others that will become apparent with reference to the following specification, the present invention provides methods for processing an amorphous silicon thin film sample into a polycrystalline silicon thin film are disclosed. In one preferred arrangement, a method includes the steps of generating a sequence of excimer laser pulses, controllably modulating each excimer laser pulse in the sequence to a predetermined fluence, homoginizing each modulated laser pulse in the sequence in a predetermined plane, masking portions of each homoginized fluence controlled laser pulse in the sequence with a two dimensional pattern of slits to generate a sequence of fluence controlled pulses of line patterned beamlets, each slit in the pattern of slits being sufficiently narrow to prevent inducement of significant nucleation in region of a silicon thin film sample irradiated by a beamlet corresponding to the slit, irradiating an amorphous silicon thin film sample with the sequence of fluence controlled slit patterned beamlets to effect melting of portions

thereof corresponding to each fluence controlled patterned beamlet pulse in the sequence of pulses of patterned beamlets, and controllably sequentially translating a relative position of the sample with respect to each of the fluence controlled pulse of slit patterned beamlets to thereby process the amorphous silicon thin film sample into a single or polycrystalline silicon thin film.

In a preferred arrangement, the masking step includes masking portions of each homoginized fluence controlled laser pulse in said sequence with a two dimensional pattern of substantially parallel straight slits spaced a predetermined distance apart and linearly extending parallel to one direction of said plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets. Advantageously, the translating provides for controllably sequentially translating the relative position of the sample in a direction perpendicular to each of the fluence controlled pulse of slit patterned beamlets over substantially the predetermined slit spacing distance, to the to thereby process the amorphous silicon thin film sample into polycrystalline silicon thin film having long grained, directionally controlled crystals.

In an especially preferred arrangement, the masking step comprises masking portions of each homoginized fluence controlled laser pulse in the sequence with a two dimensional pattern of substantially parallel straight slits of a predetermined width, spaced a predetermined distance being less than the predetermined width apart, and linearly extending parallel to one direction of the plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets. In this arrangement, translating step comprises translating by a distance less than the predetermined width the relative position of the sample in a direction perpendicular to each of the fluence controlled pulse of slit patterned beamlets, to the to thereby process the amorphous silicon thin film sample into polycrystalline silicon thin film having long grained, directionally controlled crystals using just two laser pulses. In one exemplary embodiment, the predetermined width is approximately 4 micrometers, the predetermined spacing distance is approximately 2 micrometers, and the translating distance is approximately 3 micrometers.

In an alternative preferred arrangement, the masking step comprises masking portions of each homoginized fluence controlled laser pulse in the sequence

with a two dimensional pattern of substantially parallel straight slits spaced a predetermined distance apart and linearly extending at substantially 45 degree angle with respect to one direction of the plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets. In this arrangement, the translating step provides for controllably sequentially translating the relative position of the sample in a direction parallel to the one direction of the plane of homoginization over substantially the predetermined slit distance, to thereby process the amorphous silicon thin film sample into polycrystalline silicon thin film having long grained, directionally controlled crystals that are disoriented with respect to the XY axis of the thin silicon film.

In yet another preferred arrangement, the masking step comprises masking portions of each homoginized fluence controlled laser pulse in the sequence with a two dimensional pattern of intersecting straight slits, a first group of straight slits being spaced a first predetermined apart and linearly extending at substantially 45 degree angle with respect to a first direction of the plane of homoginization, and a second group of straight slits being spaced a second predetermined distance apart and linearly extending at substantially 45 degree angle with respect to a second direction of the plane of homoginization and intersecting the first group at substantially a 90 degree angle, to generate a sequence of fluence controlled pulses of slit patterned beamlets. The corresponding translating step provides for controllably sequentially translating the relative position of the sample in a direction parallel to the first direction of the plane of homoginization over substantially the first predetermined slit spacing distance, to thereby process the amorphous silicon thin film sample into polycrystalline silicon thin film having large diamond shaped crystals.

In still another alternative arrangement, the masking step comprises masking portions of each homoginized fluence controlled laser pulse in the sequence with a two dimensional pattern of sawtooth shaped slits spaced a predetermined distance apart and extending generally parallel to one direction of the plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets. In this arrangement, the translating step provides for controllably sequentially translating the relative position of the sample in a direction perpendicular to each of the fluence controlled pulse of slit patterned beamlets over substantially the predetermined slit

spacing distance, to the to thereby process the amorphous silicon thin film sample into polycrystalline silicon thin film having large hexagonal crystals.

In a modified arrangement, an alternative technique for processing an amorphous silicon thin film sample into a polycrystalline silicon thin film using a polka-dot pattern is provided. Te technique includes generating a sequence of excimer laser pulses, homoginizing each laser pulse in the sequence in a predetermined plane, masking portions of each homoginized laser pulse in the sequence with a two dimensional pattern of substantially opaque dots to generate a sequence of pulses of dot patterned beamlets, irradiating an amorphous silicon thin film sample with the sequence of dot patterned beamlets to effect melting of portions thereof corresponding to each dot patterned beamlet pulse in the sequence of pulses of patterned beamlets, and controllably sequentially translating the sample relative to each of the pulses of dot patterned beamlets by alternating a translation direction in two perpendicular axis and in a distance less than the super lateral grown distance for the sample, to thereby process the amorphous silicon thin film sample into a polycrystalline silicon thin film.

The accompanying drawings, which are incorporated and constitute part of this disclosure, illustrate a preferred embodiment of the invention and serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a functional diagram of a system for performing the lateral solidification process preferred to implement a preferred process of the present invention;

Fig. 2a is an illustrative diagram showing a mask having a dashed pattern;

Fig. 2b is an illustrative diagram of a crystallized silicon film resulting from the use of the mask shown in Fig. 2a in the system of Fig. 1;

Fig. 3a is an illustrative diagram showing a mask having a chevron pattern;

Fig. 3b is an illustrative diagram of a crystallized silicon film resulting from the use of the mask shown in Fig. 3a in the system of Fig. 1;

Fig. 4a is an illustrative diagram showing a mask having a line pattern;

Fig. 4b is an illustrative diagram of a crystallized silicon film resulting from the use of the mask shown in Fig. 4a in the system of Fig. 1;

Fig. 5a is an illustrative diagram showing irradiated areas of a silicon sample using a mask having a line pattern;

Fig. 5b is an illustrative diagram showing irradiated areas of a silicon sample using a mask having a line pattern after initial irradiation and sample translation has occurred;

Fig. 5c is an illustrative diagram showing a crystallized silicon film after a second irradiation has occurred;

Fig. 6a is an illustrative diagram showing a mask having a diagonal line pattern;

Fig. 6b is an illustrative diagram of a crystallized silicon film resulting from the use of the mask shown in Fig. 6a in the system of Fig. 1;

Fig. 7a is an illustrative diagram showing a mask having a sawtooth pattern;

Fig. 7b is an illustrative diagram of a crystallized silicon film resulting from the use of the mask shown in Fig. 7a in the system of Fig. 1;

Fig. 8a is an illustrative diagram showing a mask having a crossing diagonal line pattern;

Fig. 8b is an illustrative diagram of a crystallized silicon film resulting from the use of the mask shown in Fig. 8a in the system of Fig. 1;

Fig. 9a is an illustrative diagram showing a mask having a polka-dot pattern;

Fig. 9b is an instructive diagram illustrating mask translation using the mask of Fig. 9a;

Fig. 9c is an illustrative diagram of a crystallized silicon film resulting from the use of the mask shown in Fig. 9a in the system of Fig. 1 using the mask translation scheme shown in Fig. 9b;

Fig. 9d is an illustrative diagram of an alternative crystallized silicon film resulting from the use of the mask shown in Fig. 9a in the system of Fig. 1 using the mask translation scheme shown in Fig. 9b; and

Fig. 10 is a flow diagram illustrating the steps implemented in the system of Fig. 1.

DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides techniques for producing uniform large-grained and grain boundary location controlled polycrystalline thin film semiconductors using the sequential lateral solidification process. In order to fully understand those techniques, the sequential lateral solidification process must first be appreciated.

The sequential lateral solidification process is a technique for producing large grained silicon structures through small-scale unidirectional translation of a silicon sample in between sequential pulses emitted by an excimer laser. As each pulse is absorbed by the sample, a small area of the sample is caused to melt completely and resolidify laterally into a crystal region produced by the preceding pulses of a pulse set.

A particularly advantageous sequential lateral solidification process and an apparatus to carry out that process are disclosed in our co-pending patent application entitled "Systems and Methods using Sequential Lateral Solidification for Producing Single or Polycrystalline Silicon Thin Films at Low Temperatures," filed concurrently with the present application and assigned to the common assignee, the disclosure of which is incorporated by reference herein. While the foregoing disclosure is made with reference to the particular techniques described in our co-pending patent application, it should be understood that other sequential lateral solidification techniques could readily be adapted for use in the present invention.

With reference to Fig.1, our co-pending patent application describes as a preferred embodiment a system including excimer laser 110, energy density modulator 120 to rapidly change the energy density of laser beam 111, beam attenuator and shutter 130, optics 140, 141, 142 and 143, beam homogenizer 144, lens system 145, 146, 148, masking system 150, lens system 161, 162, 163, incident laser pulse 164, thin silicon film sample 170, sample translation stage 180, granite block 190, support system 191, 192, 193, 194, 195, 196, and managing computer 100 X and Y direction translation of the silicon sample 170 may be effected by either movement of a mask 710 within masking

system 150 or by movement of the sample translation stage 180 under the direction of computer 100.

As described in further detail in our co-pending application, an amorphous silicon thin film sample is processed into a single or polycrystalline silicon thin film by generating a plurality of excimer laser pulses of a predetermined fluence, controllably modulating the fluence of the excimer laser pulses, homoginizing the modulated laser pulses in a predetermined plane, masking portions of the homoginized modulated laser pulses into patterned beamlets, irradiating an amorphous silicon thin film sample with the patterned beamlets to effect melting of portions thereof corresponding to the beamlets, and controllably translating the sample with respect to the patterned beamlets and with respect to the controlled modulation to thereby process the amorphous silicon thin film sample into a single or polycrystalline silicon thin film by sequential translation of the sample relative to the patterned beamlets and irradiation of the sample by patterned beamlets of varying fluence at corresponding sequential locations thereon. The following embodiments of the present invention will now be described with reference to the foregoing processing technique.

Referring to Figs. 2a and b, a first embodiment of the present invention will now be described. Fig. 2a illustrates a mask 210 incorporating a pattern of slits 220. The mask 210 is preferably fabricated from a quartz substrate, and includes either a metallic or dielectric coating which is etched by conventional techniques to form a mask pattern, such as that shown in Fig.2a. Each slit 220 is of a breadth 230 which is chosen in accordance with the necessary dimensionality of the device that will be fabricated on the sample 170 in the particular location that corresponds to the slit 220. For example, the slits 220 should be approximately 25 micrometers across to fabricate a 25 micrometer semiconductor device, or in the case of a multi-part device, a channel in a device, in sample 170. The width 240 of the slit 220 is preferably between approximately two and five micrometers in order to be small enough to avoid nucleation in sample 170 and large enough to maximize lateral crystal growth for each excimer pulse. It should be understood that although Fig. 2a illustrates a regular pattern of slits 220, any pattern of slits could be utilized in accordance with the microstructures desired to be fabricated on film 170.

In accordance with the present invention, the sample 170 is translated with respect to the laser pulses 164, either by movement of masking system 150 or sample translation stage 180, in order to grow crystal regions in the sample 170. When the sample 170 is translated in the Y direction and mask 210 is used in masking system 150, a processed sample 250 having crystallized regions 260 is produced, as shown in Fig. 2b. The breadth 270 of each crystallized region will be approximately equal to the breadth 230 in the mask 210. The length 280 of each region will be approximately equal to the distance of Y translation effected by movement of the masking system 150 or translation stage 180, and as with the breadth, should be chosen in accordance with the final device characteristics. Each crystal region 260 will consist of polysilicon with long and directionally controlled grains.

Referring next to Figs. 3a and b, a second embodiment of the present invention will now be described. Fig. 3a illustrates a mask 310 incorporating a pattern of chevrons 320. The breadth 320 of each chevron side will determine the size of the ultimate single crystal region to be formed in sample 170. When the sample 170 is translated in the Y direction and mask 310 is used in masking system 150, a processed sample 350 having crystallized regions 360 is produced, as shown in Fig. 3b. Each crystal region 360 will consist of a diamond shaped single crystal region 370 and two long grained, directionally controlled polycrystalline silicon regions 380 in the tails of each chevron.

While the embodiments described with reference to Figs. 2 and 3 are advantageous to generate spatially separated devices on silicon sample 170, at least some of the silicon sample 170 is not utilized in the final semiconductor. In order to facilitate a more flexible configuration of devices that can be developed on the semiconductor sample 170, the following preferred embodiments will now be described.

Referring to Figs. 4a and b, a third embodiment of the present invention will now be described. Fig. 4a illustrates a mask 410 incorporating a pattern of slits 410. Each slit 410 should extend as far across on the mask as the homogenized laser beam 149 incident on the mask permits, and must have a width 440 that is sufficiently narrow to prevent any nucleation from taking place in the irradiated region of sample 170. The width 440 will depend on a number of factors, including the energy density of the

incident laser pulse, the duration of the incident laser pulse, the thickness of the silicon thin film sample, and the temperature and conductivity of the silicon substrate. For example, the slit should not be more than 2 micrometers wide when a 500 Angstrom film is to be irradiated at room temperature with a laser pulse of 30 ns and having an energy density that slightly exceeds the complete melt threshold of the sample.

When the sample 170 is translated in the Y direction and mask 410 is used in masking system 150, a processed sample 450 having crystallized regions 460 is produced, as shown in Fig. 4b. Each crystal region 460 will consist of long grained, directionally controlled crystals 470. Depending on the periodicity 421 of the masking slits 420 in sample 410, the length of the grains 470 will be longer or shorter. In order to prevent amorphous silicon regions from being left on sample 170, the Y translation distance must be at least as long as the distance 421 between mask lines, and it is preferred that the translation be at least one micron greater than this distance 421 to eliminate small crystals that inevitably form at the initial stage of a directionally controlled polycrystalline structure.

An especially preferred technique using a mask having a pattern of lines will next be described. Using a mask as shown in Fig. 4a where closely packed mask lines 420 having a width 440 of 4 micrometers are each spaced 2 micrometers apart, the sample 170 is irradiated with one laser pulse. As shown in Fig. 5a, the laser pulse will melt regions 510, 511, 512 on the sample, where each melt region is approximately 4 micrometers wide 520 and is spaced approximately 2 micrometers apart 521. This first laser pulse will induce the formation of crystal growth in the irradiated regions 510, 511, 512, starting from the melt boundaries 530 and proceeding into the melt region, so that polycrystalline silicon 540 forms in the irradiated regions, as shown in Fig. 5b.

In order to eliminate the numerous small initial crystals 541 that form at the melt boundaries 530, the sample 170 is translated three micrometers in the Y direction and again irradiated with a single excimer laser pulse. The second irradiation regions 551, 552, 553 cause the remaining amorphous silicon 542 and initial crystal regions 543 of the polycrystalline silicon 540 to melt, while leaving the central section 545 of the polycrystalline silicon to remain. As shown in Fig. 5c, the crystal structure which forms the central section 545 outwardly grows upon solidification of melted

regions 542, 542, so that a directionally controlled long grained polycrystalline silicon device is formed on sample 170.

Referring to Figs. 6a and b, a fourth embodiment of the present invention will now be described. Fig. 6a illustrates a mask 610 incorporating a pattern of diagonal lines 620. When the sample 170 is translated in the Y direction and mask 610 is used in masking system 150, a processed sample 650 having crystallized regions 660 is produced, as shown in Fig. 6b. Each crystal region 660 will consist of long grained, directionally controlled crystals 670.

As with the embodiment described above with respect to Figs 4a and b, the translation distance will depend on the desired crystal length. Also, the process described with reference to Figs. 5a - c could readily be employed using a mask as shown in Fig. 6a, having 4 micrometer wide lines 620 that are each spaced apart by 2 micrometers. This embodiment is especially advantageous in the fabrication of displays or other devices that are oriented with respect to an XY axis, as the polycrystalline structure is not orthogonal to that axis and accordingly, the device performance will be independent of the X or Y coordinates.

Referring next to Figs. 7a and b, a fifth embodiment of the present invention will now be described. Fig. 7a illustrates a mask 710 incorporating offset sawtooth wave patterns 720, 721. When the sample 170 is translated in the Y direction and mask 710 is used in masking system 150, a processed sample 750 having crystallized regions 760 is produced, as shown in Fig. 7b. Each crystal region 760 will consist of a row of hexagonal-rectangular crystals 770. If the translation distance is slightly greater than the periodicity of the sawtooth pattern, the crystals will be hexagons. This embodiment is beneficial in the generation of larger silicon grains and may increase device performance.

Referring next to Figs. 8a and b, a sixth embodiment of the present invention will now be described. Fig. 8a illustrates a mask 810 incorporating a diagonal cross pattern 821, 822. When the sample 170 is translated in the Y direction and mask 810 is used in masking system 150, a processed sample 850 having crystallized regions 860 is produced, as shown in Fig. 8b. Each crystal region 860 will consist of a row of diamond shaped crystals 870. If the translation distance is slightly greater than the

periodicity of the pattern, the crystals will be squares. This embodiment is also beneficial in the generation of larger silicon grains and may increase device performance.

Referring next to Figs. 9a-d, a seventh embodiment of the present invention will now be described. Fig. 9a illustrates a mask 910 incorporating a polka-dot pattern 920. The polka-dot mask 910 is an inverted mask, where the polka-dots 920 correspond to masked regions and the remainder of the mask 921 is transparent. In order to fabricate large silicon crystals, the polka-dot pattern may be sequentially translated about the points on the sample 170 where such crystals are desired. For example, as shown in Fig. 9b, the polka-dot mask may be translated 931 a short distance in the positive Y direction after a first laser pulse, a short distance in the positive X direction 932 after a second laser pulse, and a short distance in the negative Y direction 933 after a third laser pulse to induce the formation of large crystals. If the separation distance between polka-dots is greater than two times the lateral growth distance, a crystalline structure 950 where crystals 960 separated by small grained polycrystalline silicon regions 961 is generated, as shown in Fig. 9c. If the separation distance is less or equal to two times the lateral growth distance so as to avoid nucleation, a crystalline structure 970 where crystals 980 are generated, as shown in Fig. 9d.

Referring next to Fig. 10, the steps executed by computer 100 to control the crystal growth process implemented with respect to Fig. 9 will be described. Fig. 10 is a flow diagram illustrating the basic steps implemented in the system of Fig. 1. The various electronics of the system shown in Fig. 1 are initialized 1000 by the computer to initiate the process. A thin silicon film sample is then loaded onto the sample translation stage 1005. It should be noted that such loading may be either manual or robotically implemented under the control of computer 100. Next, the sample translation stage is moved into an initial position 1015, which may include an alignment with respect to reference features on the sample. The various optical components of the system are focused 1020 if necessary. The laser is then stabilized 1025 to a desired energy level and reputation rate, as needed to fully melt the silicon sample in accordance with the particular processing to be carried out. If necessary, the attenuation of the laser pulses is finely adjusted 1030.

Next, the shutter is opened 1035 to expose the sample to a single pulse of irradiation and accordingly, to commence the sequential lateral solidification process. The sample is translated in the X or Y directions 1040 in an amount less than the super lateral grown distance. The shutter is again opened 1045 to expose the sample to a single pulse of irradiation, and the sample is again translated in the X or Y directions 1050 in an amount less than the super lateral growth distance. Of course, if the sample was moved in the X direction in step 1040, the sample should be moved in the Y direction in Step 1050 in order to create a polka-dot. The sample is then irradiated with a third laser pulse 1055. The process of sample translation and irradiation 1050, 1055 may be repeated 1060 to grow the polka-dot region with four or more laser pulses.

Next, if other areas on the sample have been designated for crystallization, the sample is repositioned 1065, 1066 and the crystallization process is repeated on the new area. If no further areas have been designated for crystallization, the laser is shut off 1070, the hardware is shut down 1075, and the process is completed 1080. Of course, if processing of additional samples is desired or if the present invention is utilized for batch processing, steps 1005, 1010, and 1035 - 1065 can be repeated on each sample.

The foregoing merely illustrates the principles of the invention. Various modifications and alterations to the described embodiments will be apparent to those skilled in the art in view of the teachings herein. For example, the thin silicon film sample 170 could be replaced by a sample having pre-patterned islands of silicon film. Also, the line pattern mask could be used to grow polycrystalline silicon using two laser pulses as explained with reference to Figs. 5a-c, then rotated by 90 degrees and used again in the same process to generate an array of square shaped single crystal silicon. It will thus be appreciated that those skilled in the art will be able to devise numerous systems and methods which, although not explicitly shown or described herein, embody the principles of the invention and are thus within the spirit and scope of the invention.

CLAIMS

1. A method for processing an amorphous silicon thin film sample into a polycrystalline silicon thin film, comprising the steps of:

(a) generating a sequence of excimer laser pulses;

(b) controllably modulating each excimer laser pulse in said sequence to a predetermined fluence;

(c) homoginizing each modulated laser pulse in said sequence in a predetermined plane;

(d) masking portions of each homoginized fluence controlled laser pulse in said sequence with a two dimensional pattern of slits to generate a sequence of fluence controlled pulses of line patterned beamlets, each slit in said pattern of slits being sufficiently narrow to prevent inducement of significant nucleation in region of a silicon thin film sample irradiated by a beamlet corresponding to said slit,

(e) irradiating an amorphous silicon thin film sample with said sequence of fluence controlled slit patterned beamlets to effect melting of portions thereof corresponding to each fluence controlled patterned beamlet pulse in said sequence of pulses of patterned beamlets; and

(f) controllably sequentially translating a relative position of said sample with respect to each of said fluence controlled pulse of slit patterned beamlets to thereby process said amorphous silicon thin film sample into a single or polycrystalline silicon thin film.

2. The method of claim 1, wherein said masking step comprises masking portions of each homoginized fluence controlled laser pulse in said sequence with a two dimensional pattern of substantially parallel straight slits spaced a predetermined distance apart and linearly extending parallel to one direction of said plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets.

3. The method of claim 2, wherein said translating step comprises controllably sequentially translating said relative position of said sample in a direction perpendicular to each of said fluence controlled pulse of slit patterned beamlets over substantially said predetermined slit spacing distance, to the to thereby process said amorphous silicon thin film sample into polycrystalline silicon thin film having long grained, directionally controlled crystals.

4. The method of claim 1, wherein:

(a) said masking step comprises masking portions of each homoginized fluence controlled laser pulse in said sequence with a two dimensional pattern of substantially parallel straight slits of a predetermined width, spaced a predetermined distance being less than said predetermined width apart, and linearly extending parallel to one direction of said plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets; and

(b) said translating step comprises translating by a distance less than said predetermined width said relative position of said sample in a direction perpendicular to each of said fluence controlled pulse of slit patterned beamlets, to the to thereby process said amorphous silicon thin film sample into polycrystalline silicon thin film having long grained, directionally controlled crystals using two laser pulses.

5. The method of claim 4, wherein said predetermined width is approximately 4 micrometers, said predetermined spacing distance is approximately 2 micrometers, and said translating distance is approximately 3 micrometers.

6. The method of claim 1, wherein said masking step comprises masking portions of each homoginized fluence controlled laser pulse in said sequence with a two dimensional pattern of substantially parallel straight slits spaced a predetermined distance apart and linearly extending at substantially 45 degree angle with respect

to one direction of said plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets.

7. The method of claim 6, wherein said translating step comprises controllably sequentially translating said relative position of said sample in a direction parallel to said one direction of said plane of homoginization over substantially said predetermined slit distance, to thereby process said amorphous silicon thin film sample into polycrystalline silicon thin film having long grained, directionally controlled crystals that are disoriented with respect to the XY axis of the thin silicon film.

8. The method of claim 1, wherein:

(a) said masking step comprises masking portions of each homoginized fluence controlled laser pulse in said sequence with a two dimensional pattern of substantially parallel straight slits of a predetermined width, spaced a predetermined distance being less than said predetermined width apart, and linearly extending at substantially 45 degree angle with respect to one direction of said plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets; and

(b) said translating step comprises translating by a distance less than said predetermined width said relative position of said sample in a direction parallel to said one direction of said plane of homoginization, to the to thereby process said amorphous silicon thin film sample into polycrystalline silicon thin film having long grained, directionally controlled crystals that are disoriented with respect to the XY axis of the thin silicon film using two laser pulses.

9. The method of claim 8, wherein said predetermined width is approximately 4 micrometers, said predetermined spacing distance is approximately 2 micrometers, and said translating distance is approximately 3 micrometers.

10. The method of claim 1, wherein said masking step comprises masking portions of each homoginized fluence controlled laser pulse in said sequence with a two dimensional pattern of intersecting straight slits, a first group of straight slits being spaced a first predetermined apart and linearly extending at substantially 45 degree angle with respect to a first direction of said plane of homoginization, and a second group of straight slits being spaced a second predetermined distance apart and linearly extending at substantially 45 degree angle with respect to a second direction of said plane of homoginization and intersecting said first group at substantially a 90 degree angle, to generate a sequence of fluence controlled pulses of slit patterned beamlets.

11. The method of claim 10, wherein said translating step comprises controllably sequentially translating said relative position of said sample in a direction parallel to said first direction of said plane of homoginization over substantially said first predetermined slit spacing distance, to thereby process said amorphous silicon thin film sample into polycrystalline silicon thin film having large diamond shaped crystals.

12. The method of claim 1, wherein said masking step comprises masking portions of each homoginized fluence controlled laser pulse in said sequence with a two dimensional pattern of sawtooth shaped slits spaced a predetermined distance apart and extending generally parallel to one direction of said plane of homoginization to generate a sequence of fluence controlled pulses of slit patterned beamlets.

13. The method of claim 12, wherein said translating step comprises controllably sequentially translating said relative position of said sample in a direction perpendicular to each of said fluence controlled pulse of slit patterned beamlets over substantially said predetermined slit spacing distance, to the to thereby process said amorphous silicon thin film sample into polycrystalline silicon thin film having large hexagonal crystals.

14. A method for processing an amorphous silicon thin film sample into a polycrystalline silicon thin film, comprising the steps of:

(a) generating a sequence of excimer laser pulses;

(b) homoginizing each laser pulse in said sequence in a predetermined plane;

(c) masking portions of each homoginized laser pulse in said sequence with a two dimensional pattern of substantially opaque dots to generate a sequence of pulses of dot patterned beamlets;

(d) irradiating an amorphous silicon thin film sample with said sequence of dot patterned beamlets to effect melting of portions thereof corresponding to each dot patterned beamlet pulse in said sequence of pulses of patterned beamlets; and

(e) controllably sequentially translating said sample relative to each of said pulses of dot patterned beamlets by alternating a translation direction in two perpendicular axis and in a distance less than the super lateral grown distance for said sample, to thereby process said amorphous silicon thin film sample into a polycrystalline silicon thin film.

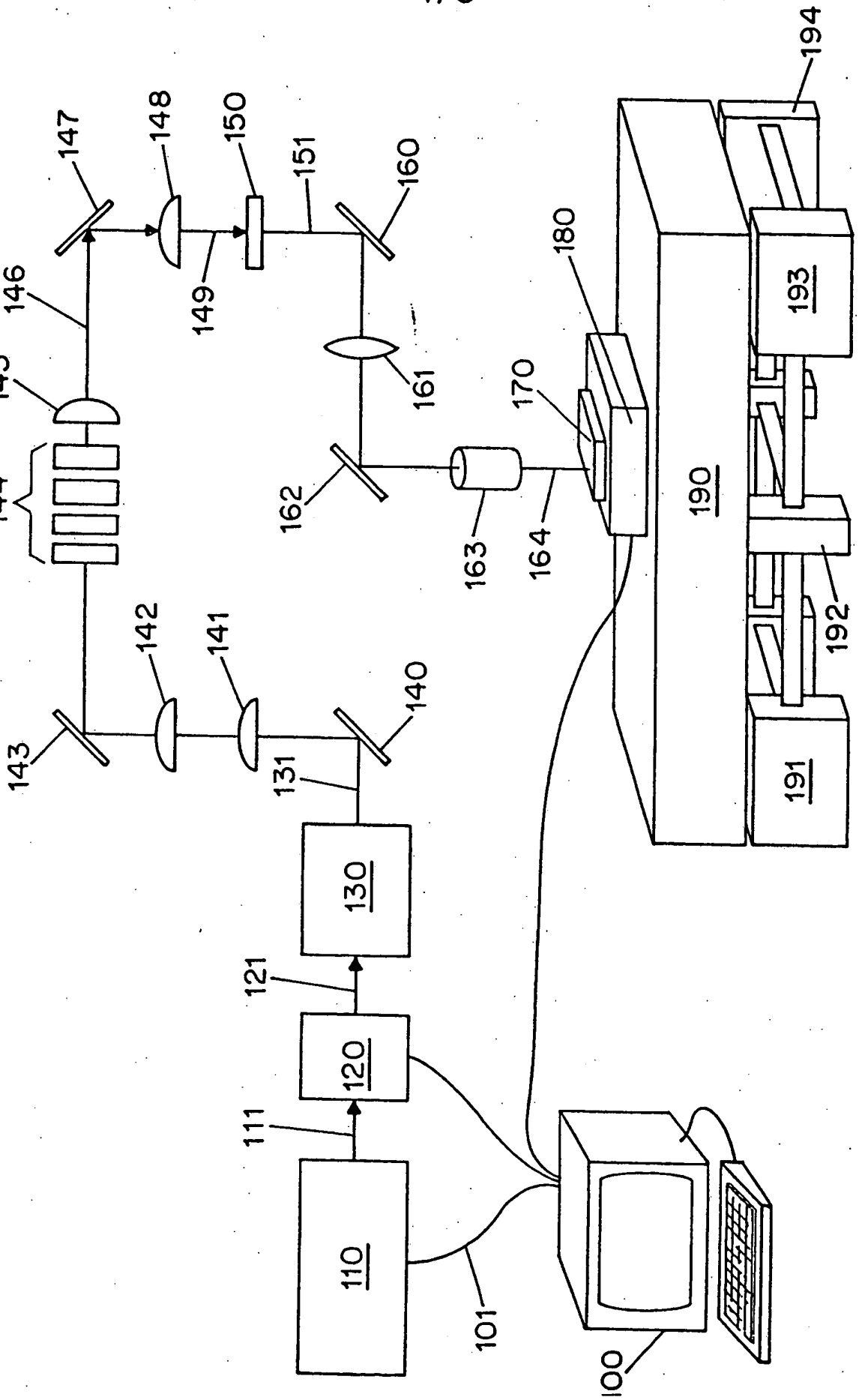
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FIG. 1

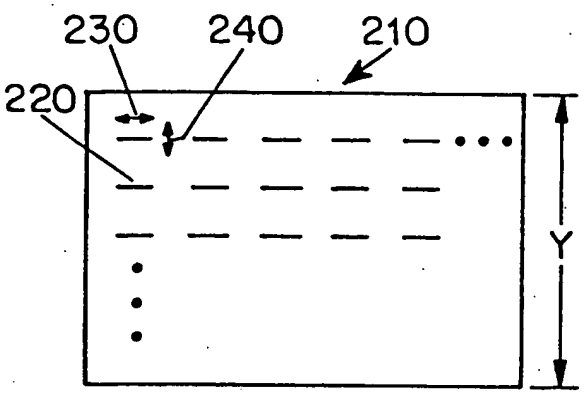

FIG. 2A

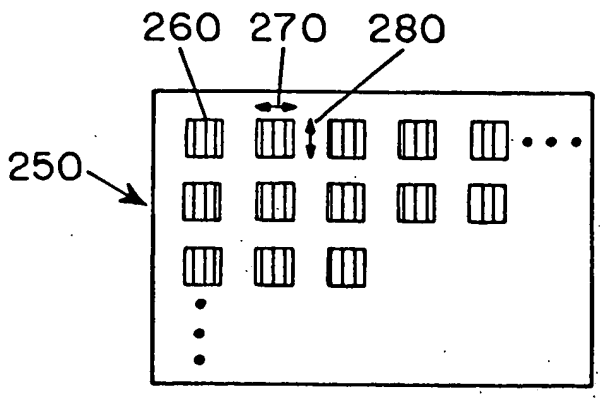

FIG. 2B

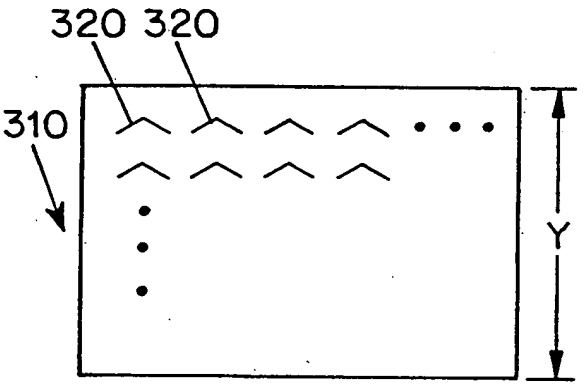

FIG. 3A

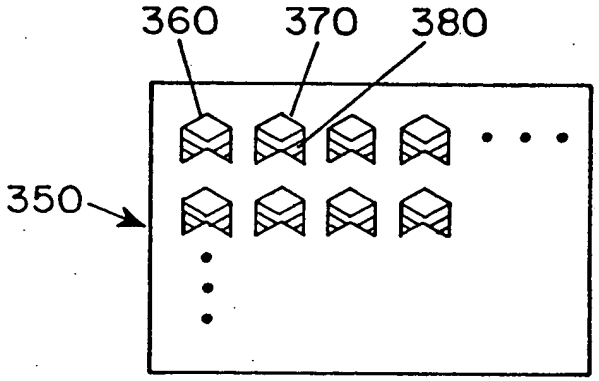

FIG. 3B

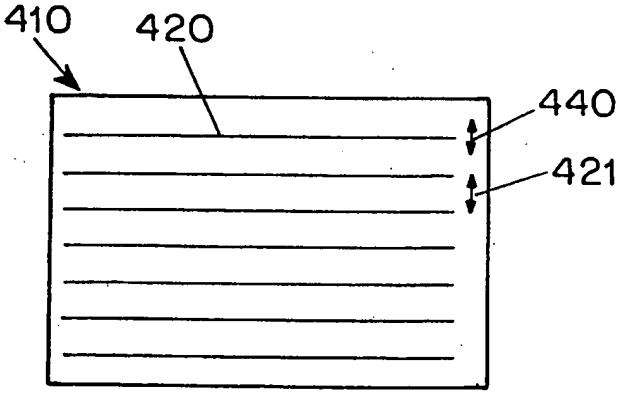

FIG. 4A

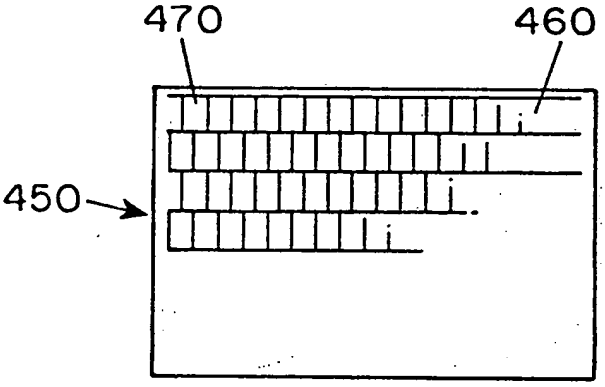

FIG. 4B

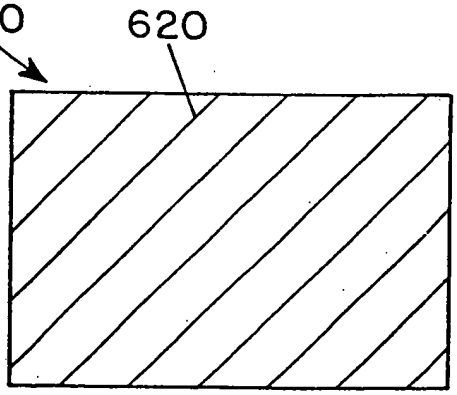

FIG. 6A

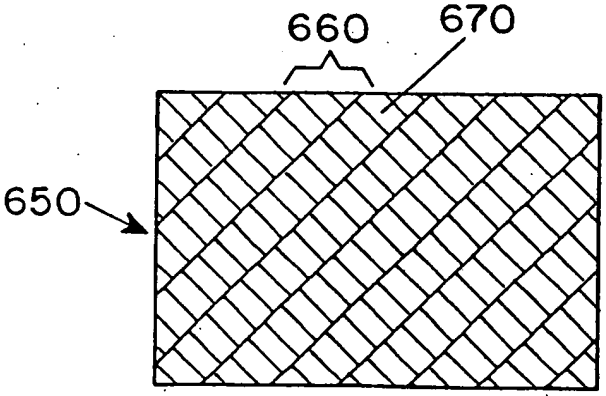

FIG. 6B

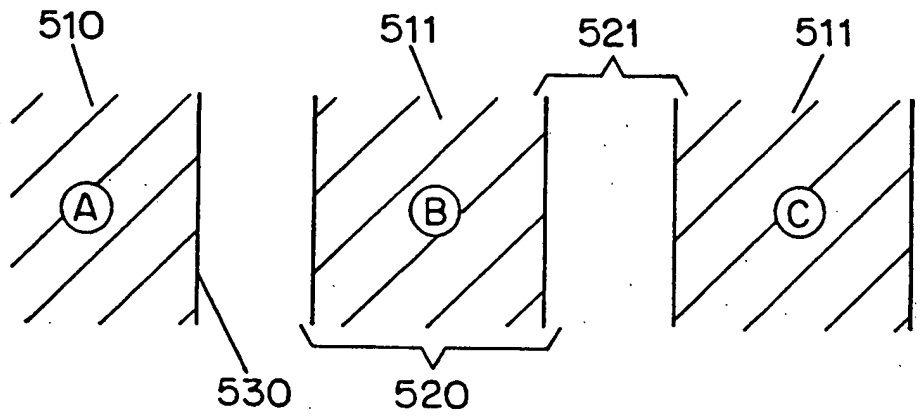

FIG. 5A

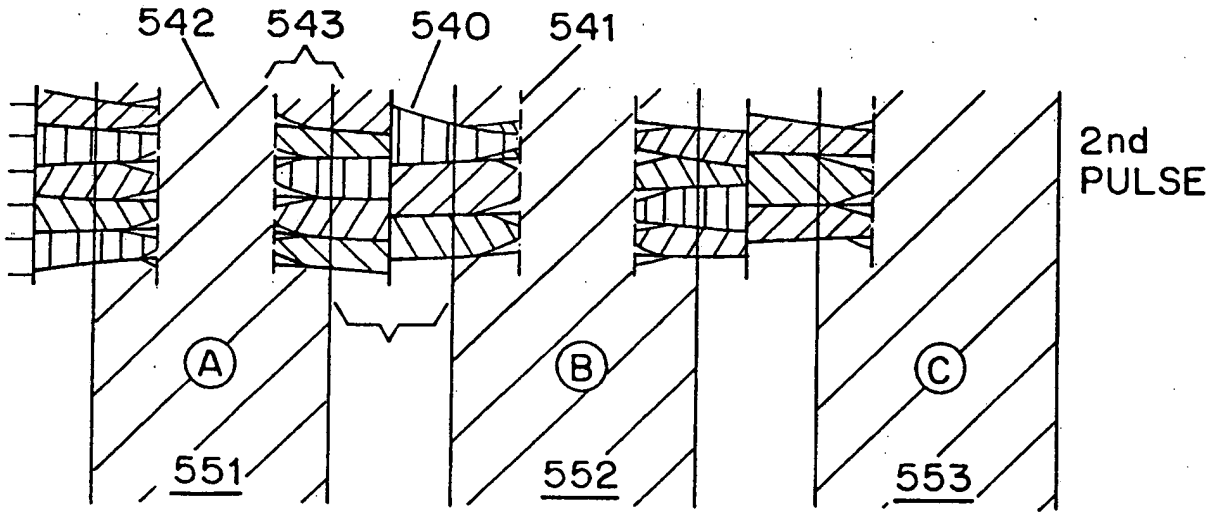

FIG. 5B

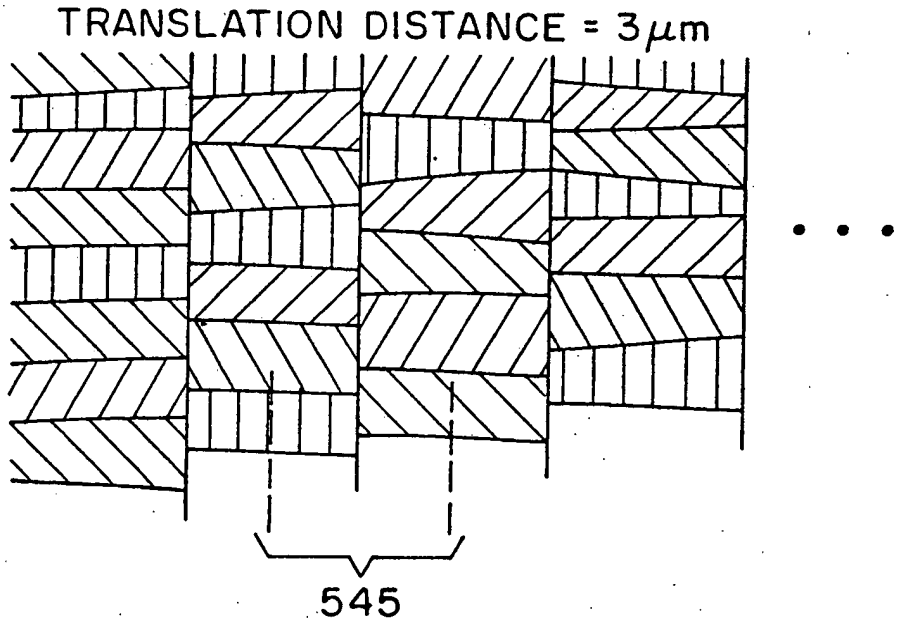

FIG. 5C

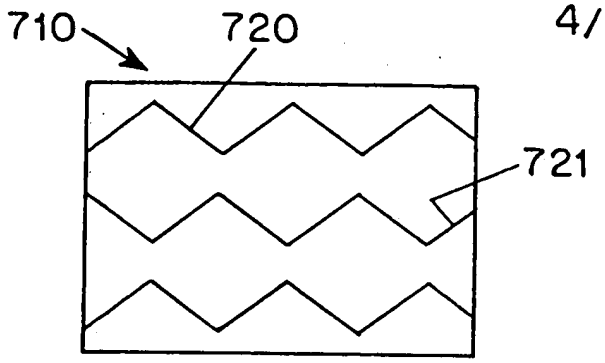

FIG. 7A

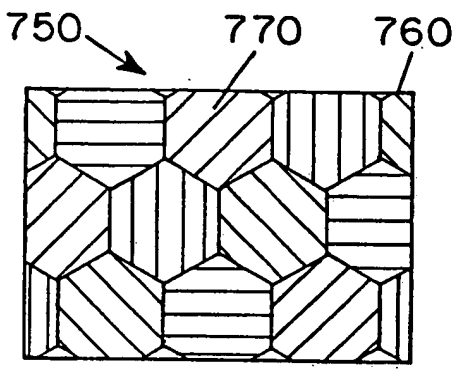

FIG. 7B

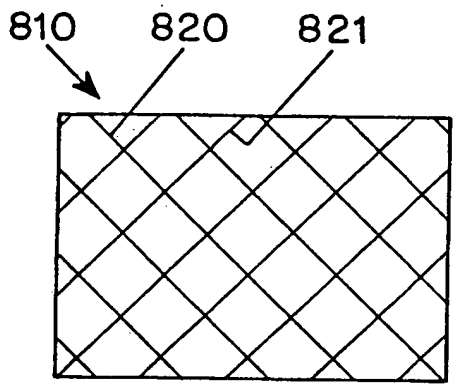

FIG. 8A

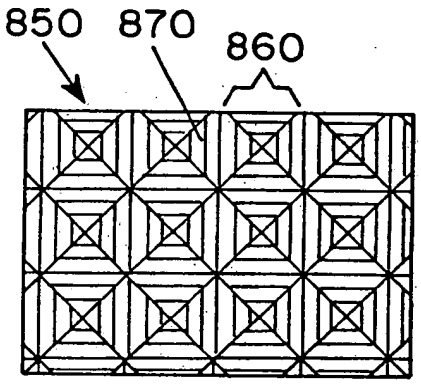

FIG. 8B

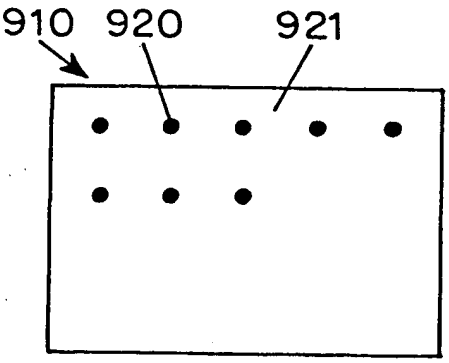

FIG. 9A

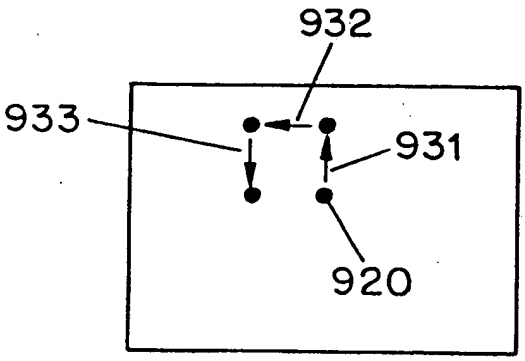

FIG. 9B

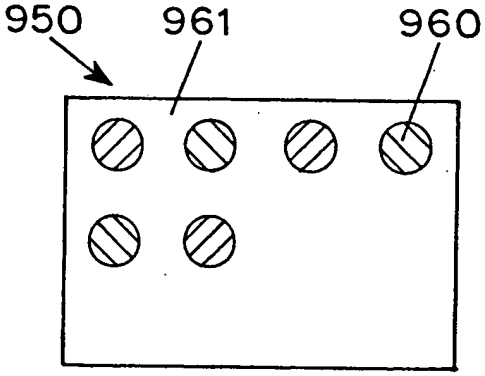

FIG. 9C

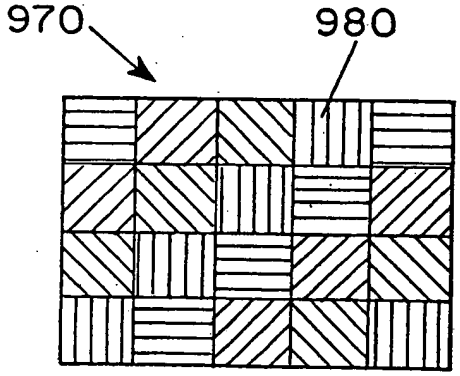

FIG. 9D

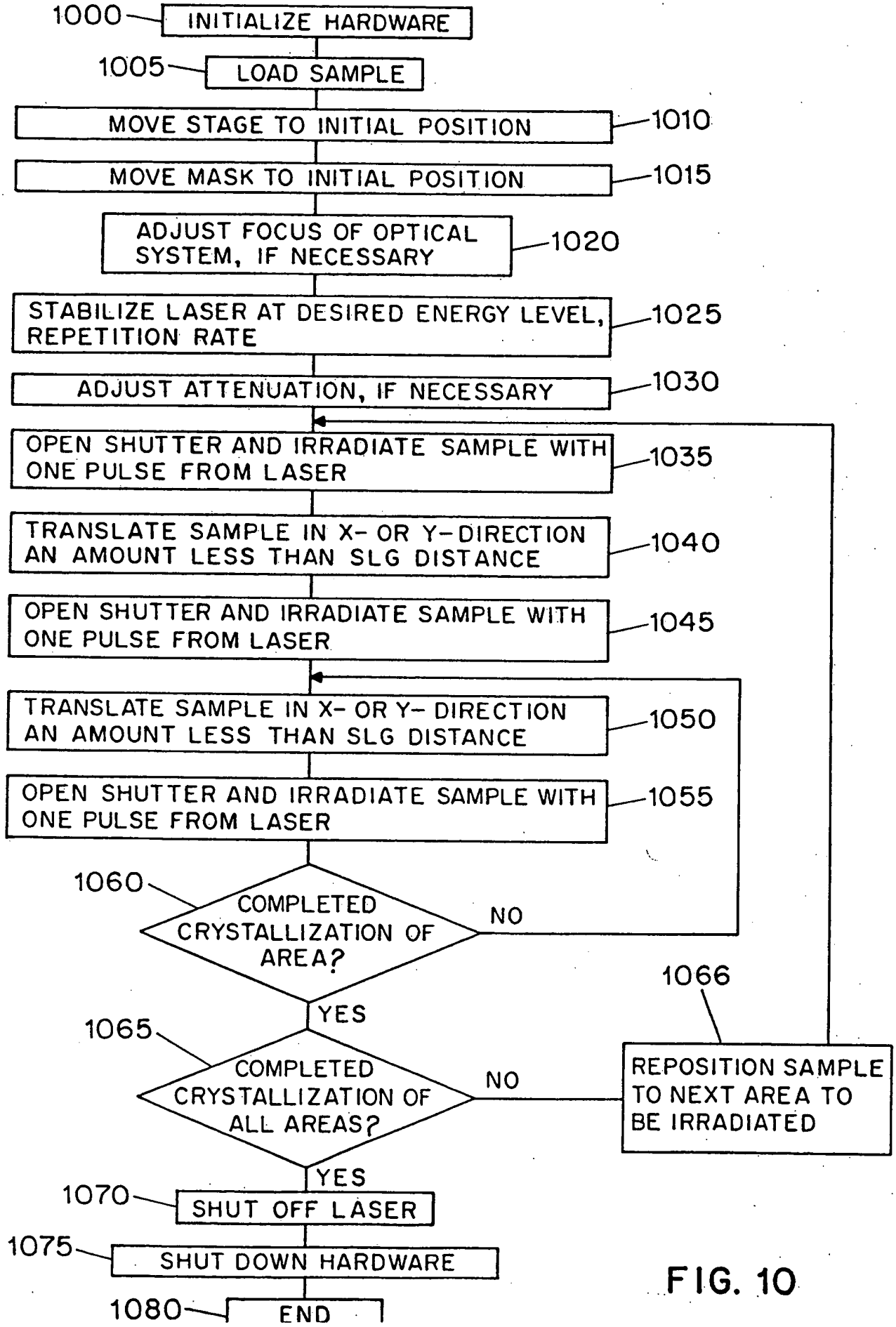
1000
INITIALIZE HARDWARE
1005
LOAD SAMPLE
MOVE STAGE TO INITIAL POSITION
1010
MOVE MASK TO INITIAL POSITION
1015
ADJUST FOCUS OF OPTICAL SYSTEM, IF NECESSARY
1020
STABILIZE LASER AT DESIRED ENERGY LEVEL, REPETITION RATE
1025
ADJUST ATTENUATION, IF NECESSARY
1030
OPEN SHUTTER AND IRRADIATE SAMPLE WITH ONE PULSE FROM LASER
1035
TRANSLATE SAMPLE IN X- OR Y-DIRECTION AN AMOUNT LESS THAN SLG DISTANCE
1040
OPEN SHUTTER AND IRRADIATE SAMPLE WITH ONE PULSE FROM LASER
1045
TRANSLATE SAMPLE IN X- OR Y- DIRECTION AN AMOUNT LESS THAN SLG DISTANCE
1050
OPEN SHUTTER AND IRRADIATE SAMPLE WITH ONE PULSE FROM LASER
1055
1060
COMPLETED CRYSTALLIZATION OF AREA?
NO
YES
1066
1065
COMPLETED CRYSTALLIZATION OF ALL AREAS?
NO
REPOSITION SAMPLE TO NEXT AREA TO BE IRRADIATED
YES
1070
SHUT OFF LASER
1075
SHUT DOWN HARDWARE
1080
END

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/23667

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H01L 21/20, 21/36
US CL :438/486, 488

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 438/486, 488

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

USPTO APS EAST
search terms: sequential, lateral, solidification, silicon, laser, crystallization

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	SPOSILI et al., Single-Crystal Si Films Via A Low-Substrate-Temperature Eximer-Laser Crystallization Method, Mat. Res. Soc. Sym. Proc. 1997, Vol. 252, pages 953-958, see entire text.	1-14
Y	IM et al., Controlled Super-Lateral Growth of Si Films for Microstructural Manipulation and Optimization, phys. stat. sol. (a) 1998, 166, pages 603-617, see entire text.	1-14

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer KEITH CHRISTIANSON

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(72) Inventor: MCCULLOCH, David, J.; Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

(74) Agent: STEVENS, Brian, T.; Internationaal Octrooibureau B.V., Prof. Holstlaan 6, NL-5656 AA Eindhoven (NL).

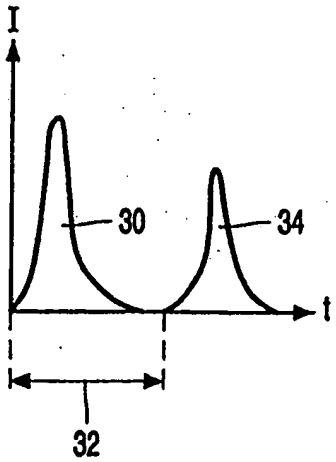
(81) Designated States: JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: DOUBLE-PULSE LASER CRYSTALLISATION OF THIN SEMICONDUCTOR FILMS

(57) Abstract

A laser crystallisation method comprises the steps of providing a film (51) of semiconductor material on an insulating substrate, and scanning a pulsed laser beam over the film, the laser beam being shaped to define a chevron (2). Each pulse of the laser beam comprises at least a first pulse portion (30) of a first energy and a second subsequent pulse portion (34) of a second energy preferably lower than the first one. The first and second pulse portions of each pulse are applied at substantially the same positionover the film (51). This method is used to form electronic devices and enables reliable crystallisation to form large single crystal areas in thin semiconductor films (51) especially of amorphous Si for TFT devices.



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DESCRIPTION

DOUBLE-PULSE LASER CRYSTALLISATION OF THIN SEMICONDUCTOR FILMS

This invention relates to laser crystallisation of thin films. Crystallisation of silicon films has been used extensively in order to produce high performance active matrix liquid crystal displays and other devices. A particular advantage of the use of laser crystallisation is that polysilicon thin film transistors can be fabricated on glass substrates, without introducing thermal damage to the glass substrate.

Various measures have been proposed in order to increase the grain size of laser crystallised silicon films, so as to reduce the number of grain boundaries occurring in devices formed from the silicon film. The article "Single-Crystal Si Films Via A Low-Substrate-Temperature Excimer-Laser Crystallization Method" in Mat. Res. Soc. Symp. Proc. Vol. 452 pp.953-958 by R. S. Sposili, et. al. describes the use of a chevron-shaped laser beam profile for the crystallisation of silicon to form single-crystal regions at predetermined locations on thin silicon films. The contents of this article are incorporated herein as reference material. The described method is applied to a film of silicon having a thickness of 200nm, and the method may practically be applied for film thicknesses down to approximately 100nm. For thicknesses below this level self-nucleation within the film results in reduction in the grain size.

It is desirable to reduce the film thickness of the semiconductor layer for various reasons. A lower thickness results in a more rapid laser crystallisation process, because a thicker semiconductor film requires more energy to melt the film. As a result, for a given energy of laser source, a smaller area of the film can be treated using the laser source. Furthermore, a thinner semiconductor film has reduced light sensitivity, which may be desirable for certain semiconductor devices.

According to a first aspect of the invention, there is provided a method of

manufacturing an electronic device comprising a semiconductor component having a thin film semiconductor layer provided on an insulating substrate, wherein the semiconductor layer is crystallised by scanning a pulsed laser beam over the film, the laser beam being shaped to define a chevron, each pulse of the laser beam comprising at least a first pulse portion of a first energy and a second subsequent pulse portion of a second energy, at least the first and second pulse portions of each pulse being applied at substantially the same position over the film. Each pulse of the chevron-shaped beam may comprise more than two pulse portions. Thus, each pulse may comprise successive pulse portions of different energies which are applied at substantially the same position over the film.

The use of a chevron-shaped crystallisation beam enables the grain size of single crystal regions in the semiconductor film to be increased. Furthermore, the use of the multiple-pulse laser reduces the tendency to self-nucleation within the semiconductor film. This enables the crystallisation method to be employed for film thicknesses below 100nm, and preferably for film thicknesses of approximately 40nm.

The invention also provides a laser crystallisation method for crystallising a thin film semiconductor layer, comprising the steps of:

providing a film of semiconductor material on an insulating substrate;

scanning a pulsed laser beam over the film, the laser beam being shaped to define a chevron, each pulse of the laser beam comprising at least a first pulse portion of a first energy and a second subsequent pulse portion of a second energy, at least the first and second pulse portions of each pulse being applied at substantially the same position over the film.

A double-pulse laser crystallisation method is known from the article "A Novel Double-Pulse Excimer-Laser Crystallization Method of Silicon Thin-Films" in Jpn. J. Appl. Phys. Vol 34 (1995) pp 3976-3981 by R. Ishihara et. al., and the method is described as increasing the grain size of excimer-laser crystallised silicon films, particularly so that a single split pulse can produce crystallisation of a 1 micrometer region of film material. The contents of this article are also incorporated herein as reference material.

The invention also provides a laser crystallisation apparatus comprising:

a pulsed laser source providing laser beam pulses;

an optical processing system for splitting the laser beam pulses to provide output pulses having an intensity profile defining at least a first pulse portion of a first energy and a second subsequent pulse portion of a second energy;

means for shaping the output pulses to form chevron-shaped pulses; and

a projection system for projecting the chevron-shaped pulses onto a sample for crystallisation.

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 shows the grain boundaries defined by a pulse laser applied to an amorphous semiconductor film, with the pulse applied through a chevron shaped mask;

Figure 2 shows laser crystallisation apparatus according to the invention; and

Figure 3 shows the laser beam intensity pattern at locations IIIA and IIIB within the apparatus of Figure 2.

As shown in Figure 1, the solidification front for a laser crystallisation technique according to the invention is defined as a chevron-shaped beam 2 which grows a single crystal grain at the apex of the chevron. The single crystal grain grows as the beam is advanced over the film. This beam shape enables large single-crystal regions to be defined within a semiconductor layer and which can be positioned to coincide with the desired locations for semiconductor devices to be formed from the film, for example thin film transistors. Each pulse of the beam comprises two pulse portions, for example having the intensity-time profile represented in Figure 3 part B. This double-pulse method enables the thickness of films which can be processed using the invention to be reduced to the optimum levels for amorphous silicon semiconductor layers, for example 40nm.

The method of the invention is applicable to laser crystallisation methods, which enable the conversion of amorphous or polycrystalline silicon films into directionally solidified microstructures. The crystallisation method involves complete melting of the selected regions of the semiconductor film using irradiation through a patterned mask, combined with controlled movement of the film relatively to the mask between pulses. For a given energy output of the laser source of the crystallisation apparatus, a thinner film thickness enables the rate at which the patterned laser is scanned over the film to be increased.

Figure 1 illustrates the crystallisation caused by advancing a laser heating beam patterned using a chevron-shaped aperture over the film of semiconductor material. The use of a chevron shaped mask 2 causes a single crystal grain to be formed at the apex of the chevron, which then experiences lateral growth not only in the translation direction (arrow 6 in Figure 1) but also transversely, due to the fact that the grain boundaries form approximately perpendicularly to the melt interface. Advancing the chevron shaped beam over the thin film semiconductor layer results in the single-crystal region 4 as shown in Figure 1 part B in the manner described in the article "Single-Crystal Si Films Via Low-Substrate-Temperature Excimer-Laser Crystallisation Method" referred to earlier in this application.

The chevron-shaped beam may have a width (W) of the order of ones or tens of microns, so that the resulting single crystal region is sufficient in size to correspond to the channel region of a thin film transistor to be fabricated using the thin film semiconductor layer. The width of the slit defining the beam shape may be approximately 1μm.

The laser may be patterned to define an array of the chevron-shaped beams so that the crystallised film includes an array of single crystal regions. The chevron-shaped beam defines first and second solidification fronts 8, 10 which meet at an apex 12. These fronts are not necessarily perpendicular, and an acute angle or an obtuse angle may be subtended at the apex. These possibilities are each intended to fall within the term "chevron" as used in this description and the claims.

Lateral solidification of the semiconductor material melted by the laser

heating is optimised when the laser heating results in complete melting of the full depth of the thin film. A sufficiently high laser energy density is required to achieve this which will depend on the film characteristics. A pulsed excimer laser is appropriate for this purpose.

The laser crystallisation method of the invention also employs a laser pulse intensity profile having two or more sequential intensity peaks. The use of double-pulse excimer laser crystallisation has already been proposed to increase the grain size of single crystal regions. The double-pulse method has been understood to slow the cooling rate, so that the crystalline nuclei can grow to a sufficient size to meet each other before the onset of copious homogeneous nucleation which is known to occur at about 500°C of undercooling. The first pulse causes the film to melt, and a sufficient time period is provided before the second pulse to allow thermal diffusion into the substrate. This pre-heating of the substrate reduces the cooling rate after the second pulse.

An example of the possible intensity profile is shown in Figure 3 part B. The first pulse 30 has a sufficient energy to density to melt completely the film, and this energy density will depend on the nature and thickness of the film being treated by the process. The energy density may be of the order of 300mJ/cm^2, for an amorphous silicon thin film having a thickness of 50nm. The pulse duration may be of the order of 30ns. The delay 32 between the pulses is sufficient to allow a significant diffusion of heat into the substrate, yet not sufficient to allow copious homogenious nucleation of the unsolidified portion of the film, and for example may be between 100 and 200ns. Less energy will be required from the second pulse 34 may have an energy density of 150mJ/cm^2 in the example shown. The purpose of the second pulse is cause the solidification process to start again.

The exact profile of the laser pulse intensity profile will be selected taking numerous considerations into account, such as the chemical composition and the mechanical structure of the film. The invention has been described in the context of producing polycrystalline silicon films from amorphous silicon deposited layers, although the invention is equally applicable to laser crystallisation of other materials.

Figure 2 shows a laser crystallisation apparatus according to the invention. A pulse laser source 40 provides laser beam pulses, for example having the profile shown in Figure 3 Part A. An optical processing system 42 provides the multiple peak intensity profile of which an example is shown in Figure 3 Part B (in which each pulse includes a first pulse portion of a first energy and a second subsequent pulse portion of a second energy). This system 42 receives the laser source output from a beam splitter 44, which is partially transmissive and partially reflective. An optical delay is provided by the processing system 42, as well as attenuation of the light signal if desired. Using a combiner 46, the delayed signal is combined with the part of the original source output transmitted by the beam splitter 44.

The double pulse laser beam output is supplied to a homogeniser 48 for conversion from a semi-gaussian profile to a top-hat profile.

As one possibility, a mask 50 is provided for shaping the output pulses to form the chevron-shaped pulses, for subsequent transmission to the sample 51, using a projection system 52.

The sample (comprising the film 51 on its insulating substrate) is mounted on a movable platform so that the projected beam can be caused to scan over the sample.

CLAIMS

1. A method of manufacturing an electronic device comprising a semiconductor component having a thin film semiconductor layer provided on an insulating substrate, wherein the semiconductor layer is crystallised by scanning a pulsed laser beam over the film, the laser beam being shaped to define a chevron, each pulse of the laser heat source comprising at least a first pulse portion of a first energy and a second subsequent pulse portion of a second energy, at least the first and second pulse portions of each pulse being applied at the substantially same position over the film.

2. A method as claimed in claim 1, wherein the semiconductor component comprises a thin film transistor.

3. A laser crystallisation method for crystallising a thin film semiconductor layer, comprising the steps of:

providing a film of semiconductor material on an insulating substrate; and

scanning a pulsed laser beam over the film, the laser beam being shaped to define a chevron, each pulse of the laser beam comprising at least a first pulse portion of a first energy and a second subsequent pulse portion of a second energy, at least the first and second pulse portions of each pulse being applied at substantially the same position over the film.

4. A method as claimed in claim 1,2 or 3, wherein thickness of the film is less than 100nm.

5. A method as claimed in claim 4, wherein thickness of the film is approximately 40nm.

6. A method as claimed in any preceding claim, wherein the first

energy is greater than the second energy.

7. A method as claimed in any preceding claim, wherein the film of semiconductor material comprises amorphous silicon.

8. A laser crystallisation apparatus comprising:

a pulsed laser source providing laser beam pulses;

an optical processing system for splitting the laser beam pulses to provide output pulses having an intensity profile defining at least a first pulse portion of a first energy and a second subsequent pulse portion of a second energy;

means for shaping the output pulses to form chevron-shaped pulses; and

a projection system for projecting the chevron-shaped pulses onto a sample for crystallisation.

9. A laser crystallisation device as claimed in claim 7, further comprising means for scanning the output pulses across the sample.

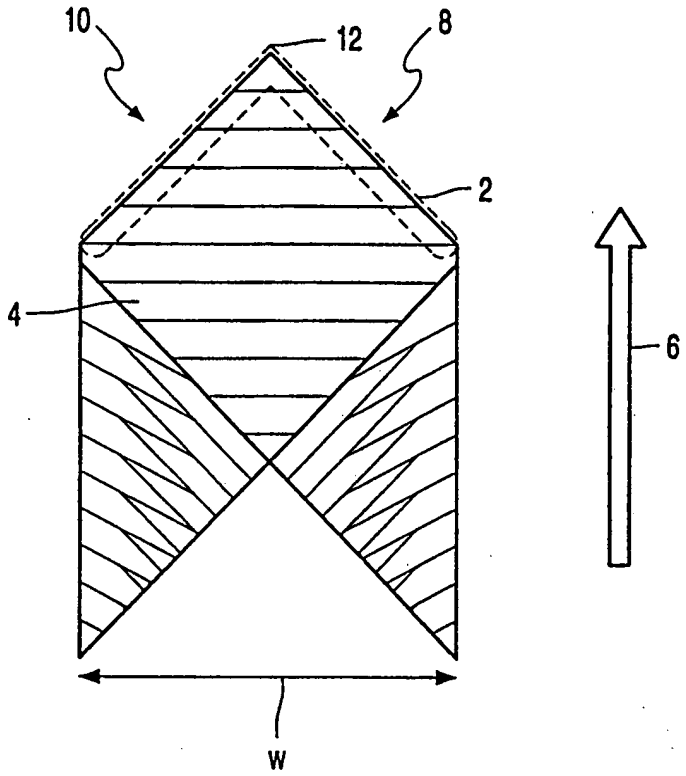
10
12
8
2
4
6
W

FIG. 1

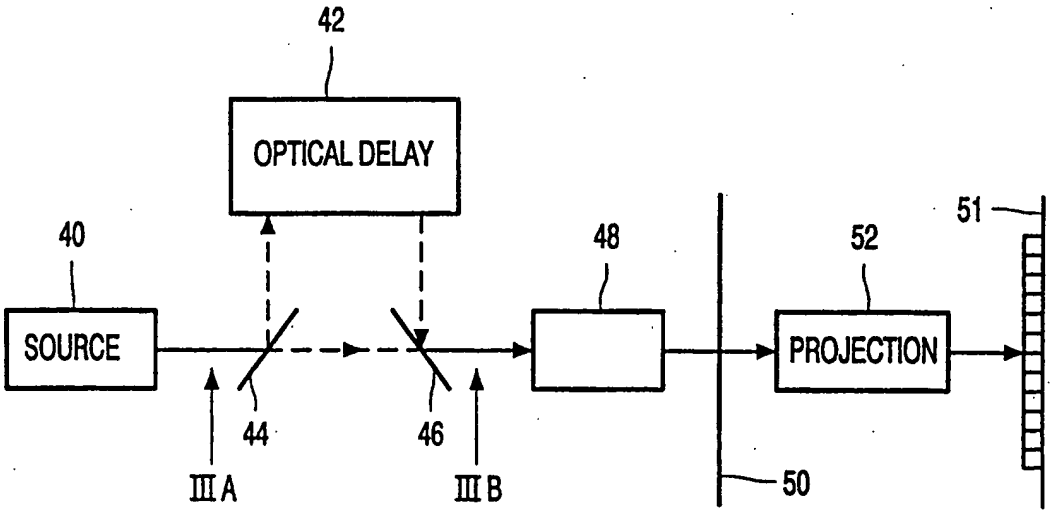
42
OPTICAL DELAY
40
48
52
51
SOURCE
PROJECTION
44
46
III A
III B
50

FIG. 2

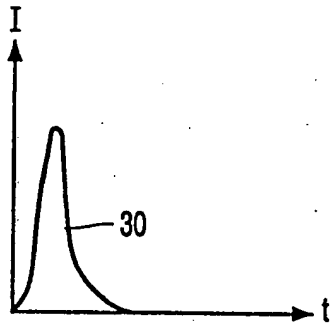

FIG. 3A

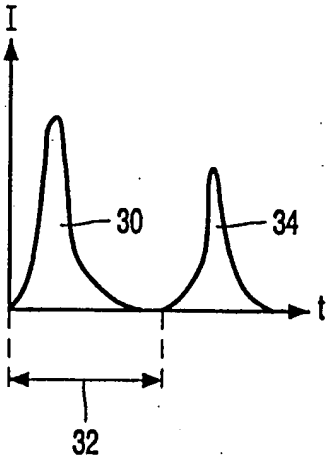

FIG. 3B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 99/06161

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/268 C30B13/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L C30B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 97 45827 A (IM JAMES S ET AL (US); COLUMBIA UNIVERSITY) 4 December 1997 (1997-12-04)	1-5,7
A	page 4, line 23 -page 5, line 18 page 11, line 23 -page 13, line 23; figures 7,8,10	8,9

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 November 1999	10/12/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,	

INTERNATIONAL SEARCH REPORT

Int ional Application No
PCT/EP 99/06161

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	ISHIHARA R ET AL: "A novel double-pulse excimer-laser crystallization method of silicon thin-films" JAPANESE JOURNAL OF APPLIED PHYSICS, PART 1 (REGULAR PAPERS & SHORT NOTES), vol. 34, no. 8A, August 1995 (1995-08), pages 3976-3981, XP000861506 ISSN: 0021-4922 cited in the application	1-5,7
A	the whole document	8,9
A	SPOSILI R S ET AL: "Single-crystal Si films via a low-substrate-temperature excimer-laser crystallization method" ADVANCES IN MICROCRYSTALLINE AND NANOCRYSTALLINE SEMICONDUCTORS 1996 SYMPOSIUM, BOSTON, MA, USA, 2 - 6 December 1996, pages 953-958, XP000856644 1997, Pittsburgh, PA, USA, Mater. Res. Soc cited in the application the whole document	1-3,7-9
A	US 4 589 951 A (KAWAMURA SEIICHIRO) 20 May 1986 (1986-05-20) column 1 -column 3; figure 5	1,3,8

INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte .onal Application No
PCT/EP 99/06161

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 9745827 A	04-12-1997	NONE	
US 4589951 A	20-05-1986	JP 58021319 A	08-02-1983
		DE 3277481 A	19-11-1987
		EP 0071471 A	09-02-1983

(19)日本国特許庁（ＪＰ）　(12)公開特許公報（Ａ）　(11)特許出願公開番号
特開2001－23920
（P2001－23920A）
(43)公開日　平成13年１月26日(2001.1.26)

(51)Int.Cl.'	識別記号	ＦＩ		テーマコード（参考）
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Ｂ２３Ｋ　26/06		Ｂ２３Ｋ　26/06	Ｊ	５Ｆ０５２
26/08		26/08	Ｆ	
Ｈ０１Ｌ　21/20		Ｈ０１Ｌ　21/20		

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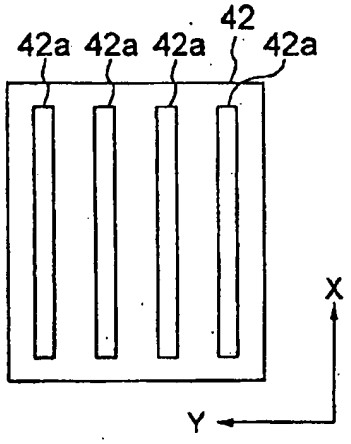
最終頁に続く

(54)【発明の名称】　レーザ加工装置

(57)【要約】
【課題】　複数のレーザ光源を組み合わせた場合にも、効率的に加工光を照射することができ、精度の高い加工を可能にするレーザ加工装置。
【解決手段】　合成光学系３０は、ナイフエッジミラー３１、３２からなり、第１ビームＬＢ1を一対のナイフエッジ３１ａ、３２ａ間に通過させるとともに第２ビームＬＢ2を一対のナイフエッジ３１ａ、３２ａによって分割する。ダイバージェンス光学系７１は第１ビームＬＢ1についてホモジナイザ４１による結像位置を微調整する。テレスコープ光学系７２は、第２ビームＬＢ2のビームサイズを第１ビームＬＢ1のビームサイズと一致させる。



【特許請求の範囲】
【請求項１】　一対の異なる光源からの一対の照射光をそれぞれ略同一サイズのビームとしてマスクに重畳して照射するビーム形成装置と、
ワークを載置するステージと、
前記マスクの像を前記ステージ上のワークに投影する投影光学系と、
前記マスクと前記ワークとを相対的に移動させる走査手段と、を備えるレーザ加工装置。
【請求項２】　前記マスクは、スリットを有し、前記走査手段は、前記マスクを前記投影光学系に対して移動させることを特徴とする請求項１記載のレーザ加工装置。
【請求項３】　前記ビーム形成装置は、前記マスクが配置される所定面上の矩形の領域に前記一対の照射光をそれぞれ入射させることを特徴とする請求項１記載のレーザ加工装置。
【発明の詳細な説明】
【０００１】
【発明の属する技術の分野】本発明は、照射光を所望のビーム形状で対象面に入射させるためのビーム形成装置を用いたレーザ加工装置に関するものであり、特にアニーリング装置、表面改質装置等に応用して好適である。
【０００２】
【従来の技術】例えばアモルファスＳｉ膜を多結晶化するレーザアニーリング装置は、アモルファスＳｉ膜を形成した基板上にアニーリング光を照射させるためのビーム整形装置として、ホモジナイザと呼ばれる光学系を備える。特に、レーザアニーリング装置が線状のレーザビームを基板上で短軸方向に１軸スキャン照射するスキャンタイプのものである場合、矩形ビームから線条ビームを形成する線条ビームホモジナイザが用られる。
【０００３】
【解決しようとする課題】しかし、上記のようなレーザアニーリング装置では、単一の光源を使用していたため、レーザ光源の特性に依存した加工光を照射せざるを得なかった。ここで、加工光の特性を多様に設定するためには、複数のレーザ光源を組み合わせることが考えられる。
【０００４】例えば一対のレーザ光源を組み合わせて合成光を得る場合、ホモジナイザに入射させる前に、偏光ビームスプリッタを用いて一対の光源からの２本のビームを重ね合わせることが考えられる。このような構成をとった場合、例えば一方の光源からの第１ビームのうちｐ偏光成分が偏光ビームスプリッタの合成面を透過してホモジナイザに入射すると考えると、他方の光源からの第２ビームのうちｓ偏光成分が、この合成部で反射されてホモジナイザに入射することになる。つまり、第１ビームのｓ偏光成分と第２ビームのｐ偏光成分とはホモジナイザに入射せず、これらの偏光成分は使用されずロスされることになる。
【０００５】そこで、本発明は、複数のレーザ光源を組み合わせた場合にも、効率的に加工光を照射することができ、精度の高い加工を可能にするレーザ加工装置を提供することを目的とする。
【０００６】
【課題を解決するための手段】上記課題を解決するため、本発明のレーザ加工装置は、一対の異なる光源からの一対の照射光をそれぞれ略同一サイズのビームとしてマスクに重畳して照射するビーム形成装置と、ワークを載置するステージと、マスクの像をステージ上のワークに投影する投影光学系と、マスクとワークとを相対的に移動させる走査手段とを備える。
【０００７】この装置では、ビーム形成装置が一対の異なる光源からの一対の照射光をそれぞれ略同一サイズのビームとしてマスクに重畳して照射するので、加工光の特性を多様に設定することができ、加工光の生成に際してのロスも少ない。
【０００８】また、上記装置の好ましい態様では、マスクが、所定方向に延びるスリットを有し、走査手段が、マスクを投影光学系に対して例えば所定方向と直交する方向に移動させる。
【０００９】この場合、マスクによって簡易に線条ビームを形成することができ、スリットの移動によってこの線条ビームをワーク上で走査することができる。
【００１０】また、上記装置の好ましい態様では、ビーム形成装置が、マスクが配置される所定面上の矩形の領域に一対の照射光をそれぞれ入射させる。
【００１１】この場合、矩形のマスクを均一かつ効率的に照明することができ、かかるマスクに形成されたパターンをワーク上に均一に投影することができる。
【００１２】
【発明の実施の形態】
【００１３】〔第１実施形態〕図１は、本発明の第１実施形態に係るレーザ加工装置であるレーザアニール装置の構造を説明する図である。このレーザアニール装置は、アモルファス状Ｓｉ等の半導体薄膜を表面上に形成したガラス板であるワークＷを載置して３次元的に滑らかに移動可能なステージ１０と、一対の特性の異なるレーザビームＬＢ1、ＬＢ2をそれぞれ発生する一対のレーザ光源２１、２２と、これらのレーザビームＬＢ1、ＬＢ2を合成する合成光学系３０と、合成光学系３０によって合成された合成光ＣＬを線条ビームＡＢにして所定の照度でワークＷ上に入射させる照射光学系４０と、照射光学系４０中に設けたマスクを移動させてワーク上に投射した線条ビームＡＢをワークＷ上で走査させる走査手段であるマスク駆動装置５０と、ワークＷを載置したステージ１０を照射光学系４０等に対して必要量だけ適宜移動させるステージ駆動装置６０と、レーザアニール装置全体の各部の動作を統括的に制御する主制御装置１００とを備える。

【００１４】一対のレーザ光源２１、２２は、ともにワークＷ上の半導体薄膜を加熱するためのエキシマレーザその他のパルス光源であり、発光時間やピーク強度、或いは波長等の特性が互いに異なる一対のレーザビームＬＢ1、ＬＢ2をそれぞれ個別に発生する。

【００１５】合成光学系３０は、両レーザ光源２１、２２からの一対のレーザビームＬＢ1、ＬＢ2を空間的に継ぎ合わせて合成光ＣＬを形成するためのもので、一対の平行に配置されたナイフエッジミラー３１、３２からなる。なお、合成光学系３０と両レーザ光源２１、２２との間には、それぞれダイバージェンス光学系７１とテレスコープ光学系７２とを調整装置として設けている。ダイバージェンス光学系７１は、レーザ光源２１からの第１ビームＬＢ1について、照射光学系４０に設けたホモジナイザ４１による光軸方向結像位置（ビーム形成位置）を微調整する調整光学系としての役割を有する。テレスコープ光学系７２は、レーザ光源２２からの第２ビームＬＢ2について、そのビームサイズを調節して合成光学系３０に入射する第１ビームＬＢ1のビームサイズと一致させるアフォーカル光学系としての役割を有する。

【００１６】図2は、合成光学系３０によって形成される合成光ＣＬを説明する図である。合成光学系３０は、レーザ光源２１からの第１ビームＬＢ1を、照射光学系４０の入射瞳Ｐのうち光軸ＯＡを含む中央側瞳領域ＣＡに入射させる。また、合成光学系３０は、レーザ光源２２からの第２ビームＬＢ2を、２つに分割し、照射光学系４０の入射瞳Ｐのうち中央側瞳領域ＣＡの両端に設けた一対の外側瞳領域ＳＡ1、ＳＡ2にそれぞれ入射させる。

【００１７】図１に戻って、照射光学系４０は、合成光学系３０からの合成光ＣＬを一旦複数に分割するとともにこれらの分割光を矩形のビームにして所定面上に重畳して均一に入射させるホモジナイザ４１と、スリット状の透過パターンを有するとともに、所定面上に配置されて合成光ＣＬを遮るマスク４２と、マスク４２に形成された透過パターンを線条ビームＡＢとしてワークＷ上に縮小投影する投影レンズ４３とを備える。

【００１８】図3は、マスク４２に形成された透過パターンを説明する図である。図からも明らかなように、マスク４２には、透過パターンとして例えばＸ方向に延びる複数のスリット４２ａが形成されている。マスク４２が図１のマスク駆動装置５０に駆動されてＹ方向に滑らかに移動すると、ワークＷ上に投影されてＸ方向に延びる線条ビーム（スリット像）ＡＢは、その長手方向に直交するＹ方向に走査される。なお、かかる走査に際してマスク４２をＹ方向に移動させる量は、これらスリット４２ａ設ける周期距離とする。

【００１９】図１に戻って、ステージ駆動装置６０は、ステージ１０を駆動してワークＷ上の所定領域を照射光学系４０に対して位置合わせするアライメントを行う。また、ステージ駆動装置６０は、マスク駆動装置５０によって線条ビームＡＢがワークＷ上の所定領域で走査されて所定領域のレーザアニールが終了した段階で、ワークＷを上記の所定領域に隣接する領域にステップ移動させるアライメントを行う。なお、ステージ駆動装置６０によるステージ１０の駆動量は、位置検出装置８０によって常時監視されている。

【００２０】以下、図１の装置の動作について説明する。まず、レーザアニール装置のステージ１０上にワークＷを搬送して載置する。次に、照射光学系４０に対してステージ１０上のワークＷをアライメントする。次に、照射光学系４０のマスク４２を移動させながら、一対のレーザ光源２１、２２から得た合成光ＣＬを線条ビームＡＢにしてワークＷ上の所定領域に入射させる。ワークＷ上には、非晶質半導体のアモルファスＳｉ等の薄膜が形成されており、線条ビームＡＢの照射及び走査によって半導体の所定領域がアニール、再結晶化され、電気的特性の優れた半導体薄膜を提供することができる。以上のようなレーザアニールは、ワークＷに設けた複数の所定領域で繰返され、ワークＷに設けた複数の所定領域で半導体薄膜がアニールされる。

【００２１】この際、上記装置では、合成光学系３０が一対のレーザ光源２１、２２からの一対のレーザビームＬＢ1、ＬＢ2を空間的に継ぎ合わせて合成光ＣＬを形成するので、一対のレーザビームＬＢ1、ＬＢ2をロスを最小限に抑えて合成することができ、合成後は、ホモジナイザ４１によって一対のレーザビームＬＢ1、ＬＢ2について均一な矩形ビームをそれぞれ所定面であるマスク４２上に形成することができる。さらに、ワークＷ上に入射する線条ビームＡＢは、レーザビームＬＢ1、ＬＢ2を効率的に合成したものであり、多様なレーザアニールが可能になる。

【００２２】図4は、合成光学系３０及びその周辺の構造を説明する図である。既に説明したように、合成光学系３０は、一対のナイフエッジミラー３１、３２からなり、第１ビームＬＢ1を一対のナイフエッジ３１ａ、３２ａ間に通過させるとともに第２ビームＬＢ2を一対のナイフエッジ３１ａ、３２ａによって分割する。第１ビームＬＢ1についてホモジナイザ４１による結像位置を微調整するダイバージェンス光学系７１は、凸レンズ７１ａと凹レンズ７１ｂとを組み合わせたアフォーカル系となっている。第２ビームＬＢ2のビームサイズを第１ビームＬＢ1のビームサイズと一致させるテレスコープ光学系７２も、凹レンズ７２ａと凸レンズ７２ｂとを組み合わせたアフォーカル系となっている。テレスコープ光学系７２と合成光学系３０との間には、ターンミラー３３を設けて第２ビームＬＢ2を案内している。一方、両レーザビームＬＢ1、ＬＢ2を合成した合成光ＣＬが入射するホモジナイザ４１は、第１～第４シリンドリカル

レンズアレイＣＡ1～ＣＡ4と、凸レンズのコンデンサレンズ４１ａとからなる。ここで、第１及び第３シリンドリカルレンズアレイＣＡ1、ＣＡ3は、紙面に平行な断面に曲率を有し、第２及び第４シリンドリカルレンズアレイＣＡ2、ＣＡ4は、紙面に垂直で光軸を含む断面に曲率を有する。

【００２３】以下、動作の概要について説明する。第１ビームＬＢ1は、ナイフエッジ３１ａ、３２ａ間、すなわちホモジナイザ４１の光軸ＯＡを含む中央側瞳領域を通り、第２ビームＬＢ2は、ナイフエッジミラー３１、３２によって２つに分割されて第１ビームＬＢ1の両端、すなわちホモジナイザ４１の一対の外側瞳領域を通って、それぞれホモジナイザ４１に入射する。ホモジナイザ４１は、合成光ＣＬが入射できるようにビーム２つ分の入射瞳のサイズにしてあり、コンデンサレンズ４１ａ等のレンズ系はその入射瞳に合わせて収差補正がされている。

【００２４】ホモジナイザ４１に入射した合成光ＣＬは、第１～第４シリンドリカルレンズアレイＣＡ1～ＣＡ4によって、シリンドリカルレンズを構成するセグメント数に分割された２次光源を形成する。分割された２次光源からの光ビームは、コンデンサレンズ４１ａに入射し、コンデンサレンズ４１ａのバックフォーカス位置に配置された被照射面ＩＳで重ね合わされて均一な矩形ビームを形成する。

【００２５】ここで、ダイバージェンス光学系７１やテレスコープ光学系７２は、第１ビームＬＢ1と第２ビームＬＢ2のビーム特性やその相違等に起因して、ホモジナイザ４１によって形成される矩形ビームについてフォーカス位置の違いやビームサイズの違い、さらにユニフォーミティの違いが生じてしまうことを防止している。

【００２６】前者のダイバージェンス光学系７１は、ホモジナイザ４１に入射する第１ビームＬＢ1のＮＡを僅かに変えてホモジナイザ４１によるベストフォーカス位置及びビームサイズを調整する。後者のテレスコープ光学系７２は、ホモジナイザ４１に入射する第１ビームＬＢ1のビームサイズに第２ビームＬＢ2のビームサイズを一致させる。これにより、両レーザビームＬＢ1、ＬＢ2について、シリンドリカルレンズアレイＣＡ1～ＣＡ4による分割数を一致させて同様のユニフォーミティを得ることができる。

【００２７】以下、動作の詳細について説明する。第１ビームＬＢ1は、図示してないビームデリバリー（ターンミラー等）を経て第１ビーム用のダイバージェンス光学系７１に入射する。このダイバージェンス光学系７１は、ほぼ等倍のアフォーカル系であり、２つのレンズ７１ａ、７１ｂのレンズ間距離を変えることにより、このダイバージェンス光学系７１から出射する第１ビームＬＢ1のビームサイズをほとんど変えることなく、この第１ビームＬＢ1のＮＡを僅かに変えることができる。具体的な実施例では、ダイバージェンス光学系７１による出射ＮＡ（第１ビームＬＢ1の広がり角）の可変調節範囲を数ｍｒａｄ程度とした。なお、２枚のレンズ７１ａ、７１ｂは凸凹の２群系であり、各々のパワーも小さいため、両レンズ７１ａ、７１ｂの間隔を変えても収差の変化はほとんど生じない。

【００２８】ダイバージェンス光学系７１を出射した第１ビームＬＢ1は、２枚のナイフエッジミラー３１、３２の間、すなわちホモジナイザ４１の光軸中心側を通過するのみである。ナイフエッジミラー３１、３２間を通過した第１ビームＬＢ1は、その後ホモジナイザ４１のシリンドリカルレンズアレイＣＡ1の中央部（第１ビームＬＢ1に割り当てられたシリンドリカルレンズ）に入射し、シリンドリカルレンズの個数（図４では６本）に分割される。分割された各ビームは、コンデンサレンズ４１ａにより重ね合わされて被照射面ＩＳで均一ビームを形成する。

【００２９】一方、第２ビームＬＢ2は、図示していないビームデリバリーを経て第２ビーム用のテレスコープ光学系７２に入射する。このテレスコープ光学系７２に入射した第２ビームＬＢ2は、本光学系で拡大または縮小されて第１ビームＬＢ1と同一のビームサイズとなってここから出射して合成光学系３０に向かう。合成光学系３０では、ナイフエッジミラー３１、３２によって第２ビームＬＢ2が２つのビーム部分ＬＢ2a、ＬＢ2bに分割され、それぞれ第１ビームＬＢ1の両端を通過してホモジナイザ４１へと向かう。両ビーム部分ＬＢ2a、ＬＢ2bは、ホモジナイザ４１の光軸中心の外側、すなわちホモジナイザ４１のシリンドリカルレンズアレイＣＡ1の両端部（第２ビームＬＢ2に割り当てられたシリンドリカルレンズ）に入射し、シリンドリカルレンズの個数（図４では上下３本ずつの計６本）に分割される。分割された各ビームは、コンデンサレンズ４１ａにより重ね合わせられて被照射面ＩＳで均一ビームを形成する。

【００３０】以上の説明では、第１ビームＬＢ1及び第２ビームＬＢ2共に「被照射面ＩＳで均一ビームを形成する」と記したが、実は両者のベストフォーカス位置は、主に光源から出射するビームの拡がり角等の特性の違いにより異なることがある。また、このようにベストフォーカスが異なっている場合、ビームサイズも異なっていることが多い。したがって、第１ビームＬＢ1及び第２ビームＬＢ2の特性の差を補償する必要がある。このため、第２ビームＬＢ2のベストフォーカス位置を真の被照射面ＩＳ（基準面）として、この基準面に第１ビームＬＢ1のベストフォーカス位置を一致させる。具体的には、ダイバージェンス光学系７１により第１ビームＬＢ1の出射ＮＡ、すなわちホモジナイザ４１から見た場合の入射ＮＡを変える。ホモジナイザ４１から見た入射ＮＡを変更すると、それに応じてホモジナイザ４１通過後のベストフォーカス位置が変わる。これにより、第

1ビームLB1のベストフォーカス位置を微調し、第2ビームLB2のそれに一致させることができる。なお、ホモジナイザ41のレンズ構成によって出射NAとベストフォーカス位置のずれとの対応は異なるのでかかる調整の詳細な説明は省略する。

【0031】〔第2実施形態〕以下、第2実施形態のレーザ加工装置について説明する。第2実施形態の装置は、第1実施形態の装置の一部として組み込まれたビーム形成装置を変形したものであり、同一部分には同一の符号を付して重複説明を省略する。図5は、ビーム形成装置の要部を説明する図である。このビーム形成装置は、第1実施形態の図4に対応するものであるが、同図において第1ビームLB1の光路中に配置されているダイバージェンス光学系71を除いた構成となっている。

【0032】この場合、テレスコープ光学系72を構成する一対のレンズ72a、72bのレンズ間隔を変えることにより、ホモジナイザ41に入射する第2ビームLB2のNAを微妙に変えることができる。この実施形態では、テレスコープ光学系72が、図4の第1ビーム用のダイバージェンス光学系71の役割、すなわち第1ビームLB1と第2ビームLB2とのフォーカス位置の調整も行う。

【0033】〔第3実施形態〕以下、第3実施形態のレーザ加工装置について説明する。第3実施形態の装置は、第1実施形態の装置の一部を変形したものである。図6は、第3実施形態のレーザ加工装置を構成するビーム形成装置の要部を説明する図である。このビーム形成装置は、第1実施形態の図4に対応するものであるが、同図において第2ビームLB2中に配置されているテレスコープ光学系72を除いた構成となっている。

【0034】使用する2つのレーザビームLB1、LB2のビームサイズがほとんど同じ場合、ビームサイズを一致させるための図4に示すようなテレスコープ光学系72を配置する必要がなくなる。また、使用する2つのレーザビームLB1、LB2のビームサイズが異なっていてもよい用途の場合も、図4に示すようなテレスコープ光学系72は不要となる。

【0035】〔第4実施形態〕以下、第4実施形態のレーザ加工装置について説明する。第4実施形態の装置は、第1実施形態の装置の一部を変形したものである。図7は、第4実施形態のビーム形成装置を構成するビーム形成装置の要部を説明する図である。このビーム形成装置では、分割光学系130として、一対のナイフエッジミラーの代わりにナイフエッジプリズム135を用いる。ホモジナイザ41通過後のビームの均一性に関して対称性等が問題にならない場合、本実施形態のようにナイフエッジプリズム135のナイフエッジ部135aを利用して、ホモジナイザ41の光軸OAから上側に第1ビームLB1を入射させ、ホモジナイザ41の光軸OAから下側に第2ビームLB2を入射させる。つまり、両レーザビームLB1、LB2を単に並べて配置しただけのものとすることができる。なお、第1ビームLB1と第2ビームLB2とを対向する方向からナイフエッジプリズム135に入射させるためのビームデリバリーについては図示を省略している。

【0036】〔第5実施形態〕以下、第5実施形態のレーザ加工装置について説明する。第5実施形態の装置は、第1実施形態の装置の一部を変形したものである。図8は、第5実施形態のレーザ加工装置を構成するビーム形成装置の要部を説明する図である。このビーム形成装置では、分割光学系230として、一対のナイフエッジミラー131、132のナイフエッジ部131a、132a同士を突き合わせるようにしたものを用いる。

【0037】以上、実施形態に即してこの発明を説明したが、本発明は、上記実施形態に限定されるものではない。上記実施形態では、ダイバージェンス光学系71やテレスコープ光学系72が球面系であるように説明したが、X軸若しくはY軸に直交する断面の一方に作用するシリンドリカルレンズ系とすることができる。シリンドリカルレンズ系とした場合は、より重要な断面に注目して、その断面でのフォーカス調整を行うことになる。通常のエキシマレーザの場合、電極方向とそれに直行する方向とでは拡がり角等のビーム特性が異なり、一方の断面に注目してシリンドリカル系を配置することが多い。さらに、両断面のベストフォーカスを個別に一致させるために、シリンドリカルレンズ系で構成したダイバージェンス光学系やテレスコープ光学系を直交する断面ごとに個別に配置しても良い。

【0038】また、上記実施形態の照射光学系40は、ホモジナイザ41によってマスク42を照明し、マスク42の像を投影レンズ43に照射することとしたが、ホモジナイザ41の被照射面ISに直接ワークWを配置することもできる。

【0039】

【発明の効果】以上の説明から明らかなように、本発明のレーザ加工装置によれば、ビーム形成装置が一対の異なる光源からの一対の照射光をそれぞれ略同一サイズのビームとしてマスクに重畳して照射するので、加工光の特性を多様に設定することができ、加工光の生成に際してのロスも少ない。

【図面の簡単な説明】

【図1】第1実施形態のレーザアニール装置の構造を示す図である。

【図2】図1の合成光学系によって形成される合成光を説明する図である。

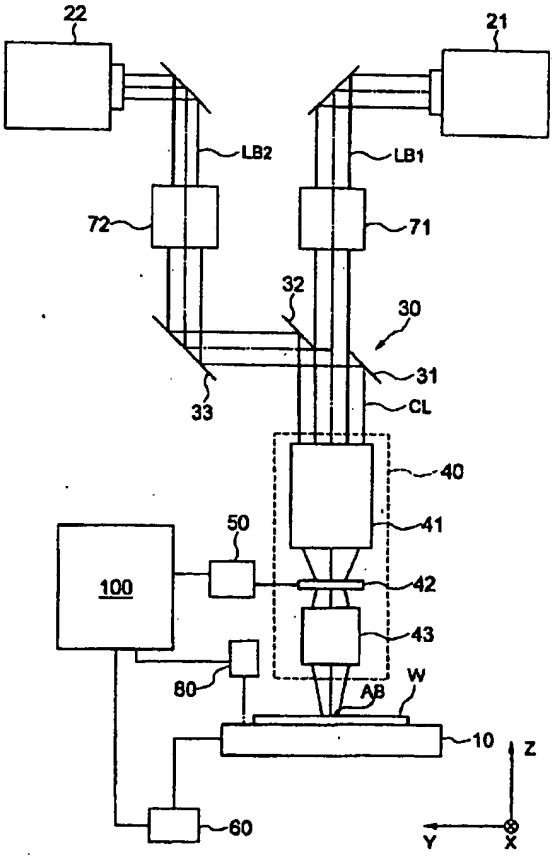
【図3】照射光学系を構成するマスクの透過パターンを説明する図である。

【図4】合成光学系30及びその周辺の詳細な構造を説明する図である。

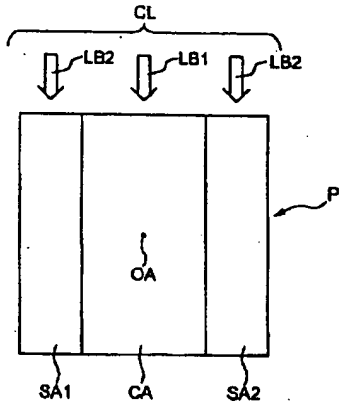
【図5】第2実施形態のビーム形成装置の要部を説明す

る図である。
【図6】第3実施形態のビーム形成装置の要部を説明する図である。
【図7】第4実施形態のビーム形成装置の要部を説明する図である。
【図8】第5実施形態のビーム形成装置の要部を説明する図である。
【符号の説明】
10　ステージ
21，22　レーザ光源
30　合成光学系
31，32　ナイフエッジミラー
40　照射光学系
41　ホモジナイザ
42　マスク
43　投影レンズ
50　マスク駆動装置
60　ステージ駆動装置
71　ダイバージェンス光学系
71a，71b　レンズ
72　テレスコープ光学系
72a，72b　レンズ
80　位置検出装置
100　主制御装置
AB　線条ビーム
CL　合成光
LB1 第1ビーム
LB2 第2ビーム
W　ワーク

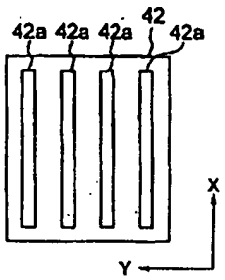
【図1】



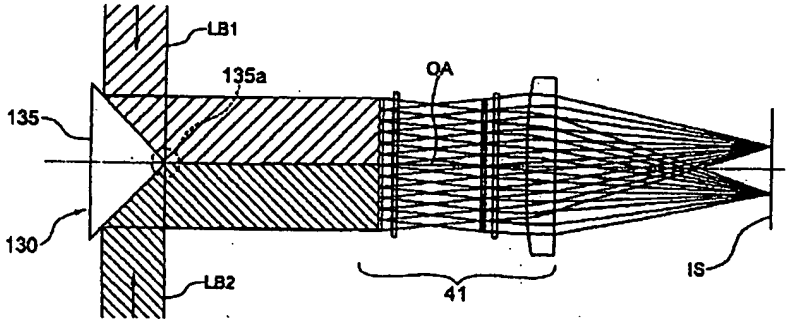
【図2】



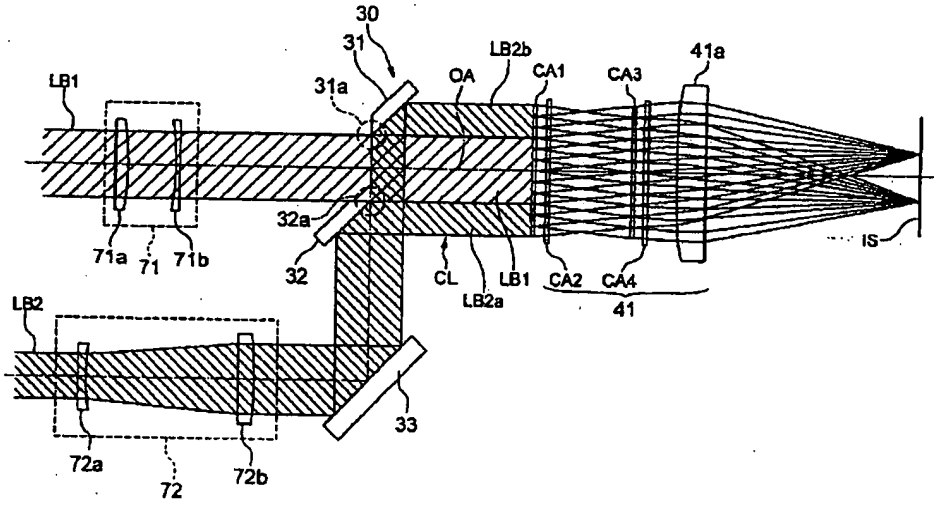
【図3】


42a 42a 42a 42 42a
X
Y

【図7】


LB1
135a
OA
135
130
LB2
41
IS

【図4】


30
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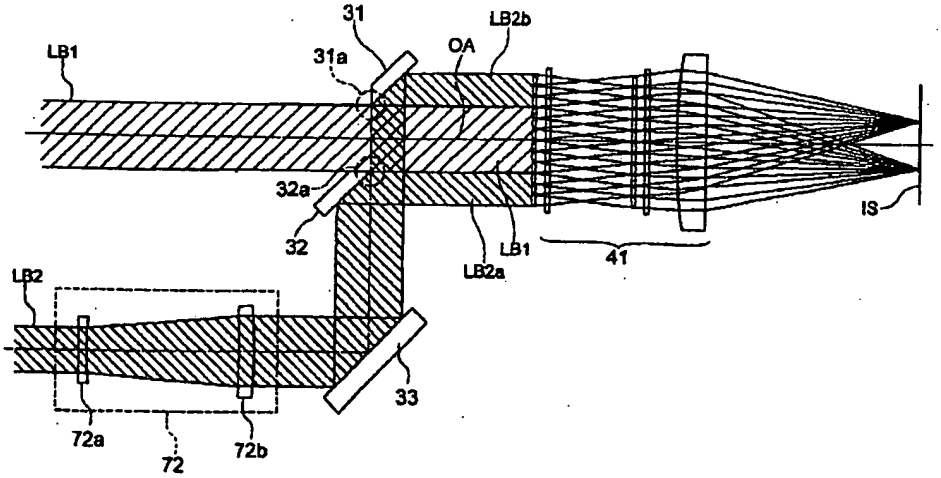
【図5】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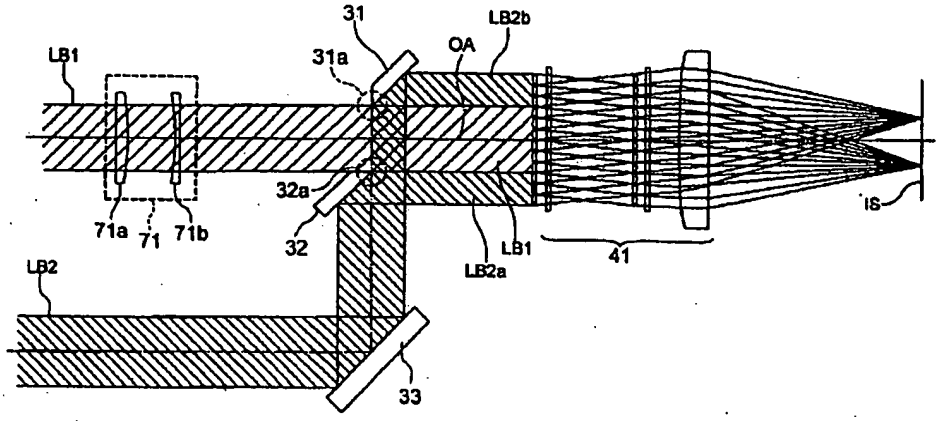
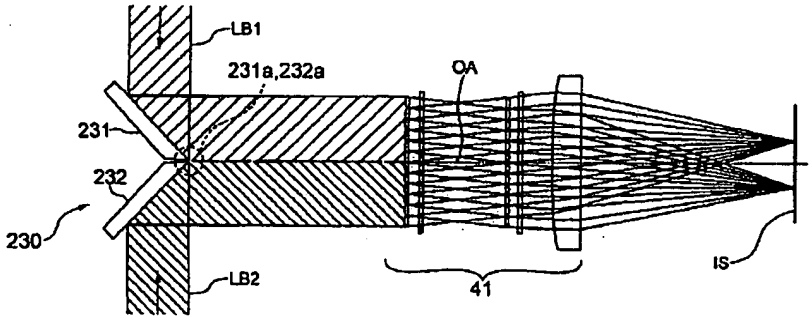
【図6】



【図8】



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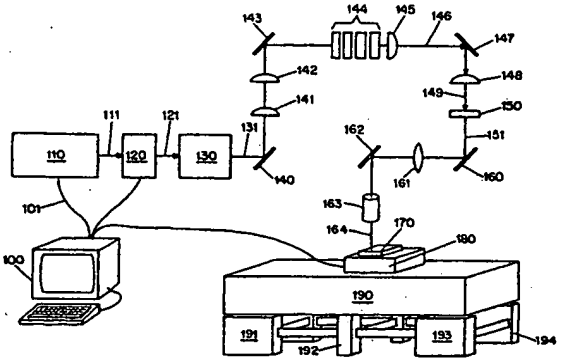
(54) Title: SYSTEMS AND METHODS USING SEQUENTIAL LATERAL SOLIDIFICATION FOR PRODUCING SINGLE OR POLYCRYSTALLINE SILICON THIN FILMS AT LOW TEMPERATURES



(57) Abstract: System and methods for processing an amorphous silicon thin film sample into a single or polycrystalline silicon thin film are disclosed. The system includes an excimer laser (110) for generating a plurality of excimer laser pulses (111) of a predetermined fluence, an energy density modulator (120) for controllably modulating fluence of the excimer laser pulses, a beam homogenizer (144) for homogenizing modulated laser pulses (146) in a predetermined plane, a mask (150) for masking portions of the homogenized modulated laser pulses into patterned beamlets, a sample stage (180) for receiving the patterned beamlets to effect melting of portions of any amorphous silicon thin film sample (170) placed thereon corresponding to the beamlets, translating means for controllably translating a relative position of the sample stage with respect to a position of the mask and a computer (100) for controlling the controllable fluence modulation of the excimer laser pulses and the controllable relative positions of the sample stage and mask, and for coordinating excimer pulse generation and fluence modulation with the relative positions of the sample stage and mask, to thereby process amorphous silicon thin film sample into a single or polycrystalline silicon thin film by sequential translation of the sample stage relative to the mask and irradiation of the sample by patterned beamlets of varying fluence

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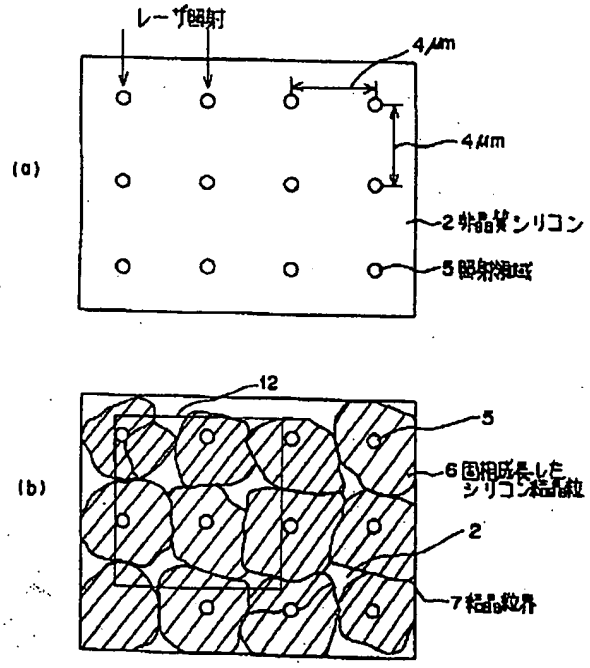
(54)【発明の名称】　薄膜トランジスタの製造方法

(57)【要約】

【目的】　選択核形成法による核形成、固相成長による多結晶シリコンの大粒径化を、リソグラフィー法を用いずに、簡易に行う。

【構成】　基板上の非晶質シリコン２に回折格子を用いてＸｅＣｌエキシマレーザを格子点状に照射する（照射領域５）。その後、窒素雰囲気中、６００度の熱処理をし、固相成長を行うことにより微結晶５を核として結晶粒が成長する。選択核形成法を用いない場合は、結晶粒径１～２μｍ程度であるが、本発明では結晶粒径は最大４μｍ程度が得られ、これをチャンネル領域とする薄膜トランジスタの移動度を８０ｃｍ²／Ｖｓから１５０ｃｍ²／Ｖｓに向上できた。



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【特許請求の範囲】

【請求項１】　非晶質半導体膜上に、特定の周期でドット状あるいはストライプ状に局所的に熱処理を施して結晶核を形成させた後、膜全体に熱処理を施して固相成長させて得られた多結晶半導体膜をチャンネル形成領域とすることを特徴とする薄膜トランジスタの製造方法。

【請求項２】　ドット状あるいはストライプ状の局所的な熱処理は、エネルギー光線を格子点状に加工して非晶質半導体膜に照射することにより行う請求項１記載の薄膜トランジスタの製造方法。

【請求項３】　ドット状あるいはストライプ状の局所的な熱処理は、エネルギー光線を集束させて非晶質半導体膜の周期的な位置に照射することにより行う請求項１記載の薄膜トランジスタの製造方法。

【発明の詳細な説明】

【０００１】

【産業上の利用分野】本発明は薄膜トランジスタの製造方法に関する。

【０００２】

【従来の技術】薄膜トランジスタは、石英ガラス等の絶縁基板上にシリコン等の半導体薄膜を形成し、チャンネルが形成されるチャンネル形成領域、ソース，ドレイン領域を形成し、ＭＯＳ型のトランジスタを構成する半導体装置である。多結晶半導体膜をチャンネル形成領域とする薄膜トランジスタは絶縁基板上に容易に形成できることから、ＳＲＡＭの負荷素子として、あるいは液晶表示装置のスイッチングトランジスタ、駆動回路等として幅広く応用されている。しかし、チャンネル形成領域の結晶粒界がトランジスタ特性を大きく低下させているので、結晶粒の大粒径化、あるいは結晶粒径、結晶粒の位置を制御する手法が広く検討されている。

【０００３】結晶粒の位置を制御する１つの方法として、特開昭６０－３７７２１号公報に開示されているような量子アニール法と呼ばれる方法がある。この方法は、レーザ光などのエネルギー光線を微細な図形に加工した光線を非晶質半導体層に照射することにより、非晶質半導体膜あるいは多結晶半導体膜を結晶化し、結晶粒の位置を制御する試みである。

【０００４】また、結晶粒径を制御する試みとして、図６に示すような選択核形成法がある。以降、図６を参照しながら選択核形成法について説明する。石英基板等の絶縁基板１上にジシランガスを用い、４７５℃程度で減圧化学成長法により非晶質シリコン２を形成する。その後、保護酸化膜３を５０ｎｍ堆積し、次いでレーザの遮光膜としてシリコン膜４を２００ｎｍスパッタ後、スパッタシリコン膜の特定部分に１μｍ以下の窓を開口する（図６（ａ））。この後、ＸｅＣｌエキシマレーザを照射する。このレーザ光では、シリコン膜での吸収係数が非常に高いので、開口部の非晶質シリコン表面部分のみがアニールされて、この領域に、微結晶シリコン核５が

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数個形成される。次に、スパッタシリコン膜４、保護酸化膜３を除去した後、６００℃の窒素中で熱処理すると、シードとなる微結晶５の周囲に結晶化した領域６が広がる（図６（ｂ））。シード領域の結晶粒の中で、成長速度の速いものが選択的に非晶質領域に広がるので、基本的には、単一あるいは２個程度の結晶粒がシード領域から発生・成長してゆくと考えて良い。このようにして膜全体の結晶化を完了させる。以上の工程は選択核形成法と呼ばれている。この方法により、結晶粒の位置を任意の場所に設定できる。また、結晶粒径はシード部分以外の核発生により制限されるが、諸条件を最適化することにより結晶粒径は４～５μｍとなり、従来の固相成長法で形成した多結晶シリコンの結晶粒径である１～２μｍに比べてはるかに大きくできる。

【０００５】その後、単結晶領域に薄膜トランジスタを以降の工程により形成する。まず、チャンネル形成領域１２を基本的には単一の結晶粒となる位置にパターンニングして形成後、ゲート酸化膜８及び多結晶シリコンを堆積した後に、リン拡散法により低抵抗化し、パターンニングしてゲート電極９を形成する。イオン注入により、ソース領域１０、ドレイン領域１１を形成する。層間膜１３を堆積した後に、９００℃程度の熱処理を施し、層間膜のリフロー、ソース，ドレイン領域の不純物の活性化を行う（図６（ｃ））。その後、コンタクトホールを開口し、アルミをスパッタリングした後にパターンニングして配線を形成し、水素雰囲気中、４００℃程度で水素アロイを行い、薄膜トランジスタを完成する。作製した薄膜トランジスタは、サイズを結晶粒径以下にすることにより、基本的には、チャンネル領域に結晶粒界を含まないようにできるので、非常に高い移動度が得られる。例えば、ｎ－ｃｈで、通常のシードを用いない方法では６０ｃｍ²／Ｖｓであったものが、この選択核成長法を用いると、１５０ｃｍ²／Ｖｓ以上と高移動度が得られる。

【０００６】

【発明が解決しようとする課題】トランジスタサイズが結晶粒径と同程度以上の場合、１つのトランジスタのチャンネル形成領域に、数個の結晶粒が存在することは不可避である。この場合、必ずしも核形成の位置自体を制御する必要はなく、結晶粒の大粒径化、チャンネル領域内の結晶粒界の密度低減が肝要である。大粒径化の方法として、量子アニール法を用いる場合は、リソグラフィー工程を用いないので、工程は簡易ではあるが、再結晶化後、シリコン膜表面にうねり、凹凸が生じ、ＴＦＴ特性の低下をもたらす。これを避けるために、非晶質シリコン上に酸化膜を堆積した後にアニールする方法が検討されているが、この方法では、酸化膜から酸素が多結晶シリコン中に拡散して、移動度を大きく低下させるという問題がある。チャンネル形成領域の単結晶化を目的とした前記のレーザ光を用いた局所アニールによる選択核

形成法では、核形成後、炉内でアニールして結晶化するために、量子アニール法で問題となるような表面荒れは起こらない。しかし、特定部分に遮光膜を設けてパターンニングするために、リソグラフィー、エッチング工程が必要であり、工程が複雑になるという問題点がある。

【０００７】本発明の目的は、このような従来の問題点を解決して、非晶質シリコンの結晶化時の結晶粒径分布および結晶粒界の位置の制御をリソグラフィー法を用いることなく簡易に行い、かくしてＴＦＴ特性の向上とばらつきの低減を図ることにある。

【０００８】

【課題を解決するための手段】本発明は、非晶質半導体膜上に、特定の周期でドット状あるいはストライプ状に局所的に熱処理を施して結晶核を形成させた後、膜全体に熱処理を施して固相成長させて得られた多結晶半導体膜をチャンネル形成領域とすることを特徴とする薄膜トランジスタの製造方法である。ここで、ドット状あるいはストライプ状の局所的な熱処理は、エネルギー光線を格子点状に加工して非晶質半導体膜に照射することにより行うか、あるいはエネルギー光線を集束させて非晶質半導体膜の周期的な位置に照射することにより行うことが好ましい。

【０００９】

【実施例】次に、本発明の実施例について図面を参照して詳細に説明する。図１は本発明の一実施例を工程順に説明するための平面図、図２は本実施例により得られる薄膜トランジスタの断面図であり、同図に従って、本実施例を説明する。石英基板１上に減圧化学成長法により、ジシランを用いて、非晶質シリコン２を８０ｎｍ堆積する。この後、図１（ａ）のように、回折格子を用いて、ＸｅＣｌエキシマレーザを格子状にホログラフィー加工して照射した。格子点間隔は１～８μｍ間隔とし（図１では４μｍ間隔のものを示した。）、ウエハ全面に照射するために、Ｘ方向、Ｙ方向にビーム照射領域が重なるようにシフトして照射した。照射エネルギーは、点状の照射領域（シード領域）５に、微結晶が数個発生するように、１８０ｍＪ／ｃｍ²に設定した。その後、窒素雰囲気中、６００℃の熱処理により、膜全体を結晶化した。結晶化は、図１（ｂ）のように、照射領域（シード領域）５内の微結晶シリコンを核として結晶成長させ、隣接するシードから成長してきた結晶粒６と接触したときに成長が停止する。以降の工程は、図１（ｂ）の枠１２をチャンネル形成領域とし、従来例と同様にして図２にその断面を示すような薄膜トランジスタを作製した。

【００１０】本実施例で得られた薄膜トランジスタの移動度とシード間隔との関係を図３に示す。図３から明らかなように、本実施例の方法では、シード間隔３μｍから７μｍまで移動度が向上し、シード間隔４μｍ程度で移動動が最大値の１４０ｃｍ²／Ｖｓとなっている。シード領域間隔が広すぎると、シード領域から核発生した結晶粒６間に残された非晶質シリコン領域２から核発生した結晶粒のために、大粒径化が妨げられ、移動度の低下をもたらすと考えられる。シード領域間隔の最適値は、シード形成の方法、非晶質シリコンの形成条件、非晶質シリコン膜厚、固相成長条件等にもよるので、それらのプロセス条件の中での最適化が必要である。

【００１１】以上述べたように、本実施例で述べた方法では、シード領域を４μｍ程度の等間隔の格子状に配置することにより、大粒径化が可能であるという特徴がある。また、この方法によれば従来例では必要であった遮光膜堆積、リソグラフィー工程、エッチング工程等の複雑な工程を必要とせず、はるかに簡易な工程で周期的なシード領域を形成できる。また、量子アニール法で問題となる表面荒れは、従来例の選択核形成法と同様に起こらない。

【００１２】なお、シード形成のためのアニール工程は、集束電子線、イオンビーム等によるアニール処理を適用してもよい。また、多結晶シリコン膜表面のみをレーザ照射により溶融させる方法を用いると、結晶粒径、配向性を変化させることなく、結晶粒内の結晶欠陥が低減できて、移動度が２００ｃｍ²／Ｖｓ程度となり、さらにＴＦＴ特性向上が可能である。

【００１３】実施例２

本発明を液晶表示装置に用いられる、駆動回路を構成するトランジスタ、及び画素部のスイッチングトランジスタに適用した例を図４を参照して説明する。下地透明基板上の画素部スイッチングトランジスタが形成される領域に、遮光膜を形成し、下地酸化膜を堆積した後に、実施例１と同様の条件で、非晶質シリコン膜を堆積する。その後、周辺駆動回路を構成するトランジスタ及び画素部トランジスタに集束電子線を照射して核形成を行った。駆動回路を構成するトランジスタはゲート長８μｍ、画素部のトランジスタはゲート長８μｍ、オフセット長１μｍとする。駆動回路トランジスタでは、核間距離は実施例１で述べたように３～７μｍに設定し、ソース端部には結晶粒界が存在し、ドレイン端部に結晶粒界が存在しない図４（ａ）の枠１２の位置になるように核形成位置を定めた。画素部トランジスタでは、ゲート端部が１つの結晶となる図４（ｂ）の枠１６の位置になるように核形成した。核形成は、すべての画素部トランジスタに核形成が行われるように、画素部トランジスタの配置周期５０μｍで、画素全領域間隔に核形成した。なお、ウエハの位置合わせは、遮光膜の層の目合わせマークを用いて行った。以降の工程は、従来の薄膜トランジスタと同様である。アルミ配線形成後に、プラズマ水素化処理を行った。

【００１４】本実施例の駆動回路を構成するトランジスタの出力特性を図５に示す。図中、（ａ）は従来例によって結晶粒界の位置を制御することなくアニールを行っ

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た場合、（ｂ）は本実施例による場合を示す。特性を比較してわかるように、移動度の増加に伴い、オン電流が増加しているだけでなく、ソース，ドレイン間耐圧が向上している。これは、アバランシェ降伏の原因となるドレイン接合部の結晶粒界の密度が低減できたこと、また、ソース接合部の結晶粒界の密度を増やすことにより、キャリアのライフタイムを短くして、寄生バイポーラ効果を低減できたためと考えられる。画素部トランジスタでは、オン電流の増加だけではなく、リーク電流が０．３ｐＡから本実施例の方法により、０．１ｐＡ以下に低減できた。これは、ドレイン側接合部の結晶粒界の密度が低減できたためと考えられる。

【００１５】

【発明の効果】以上説明したように、本発明は、非晶質半導体層を結晶化する際に、非晶質半導体層上の特定の周期で局所的に熱処理を施した後に、膜全体に熱処理を施して固相成長を行って形成する方法を用いて、局所的に熱処理した部分からの核発生・核成長を促すことにより、結晶粒が大粒径化でき、薄膜トランジスタの移動度が向上できるという効果がある。結晶粒界の位置を制御する場合は、ソースードレイン間耐圧向上、リーク電流低減の効果も有する。また、従来の選択核形成方法では必要であったリソグラフィー工程、エッチング工程等が必要でなく、工程の簡略化ができるという効果もある。＊

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＊【図面の簡単な説明】

【図１】本発明の実施例１の工程説明図である。

【図２】本発明の実施例１によって得られた薄膜トランジスタの断面図である。

【図３】移動度とシード間隔との関係を示す図である。

【図４】本発明の実施例２の説明図である。

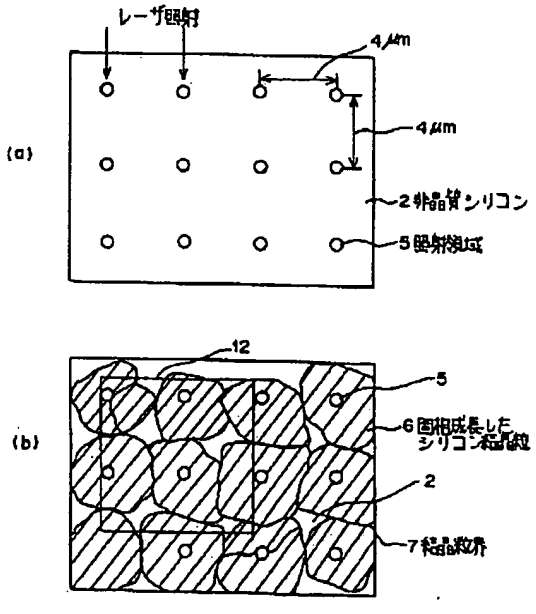
【図５】実施例２のＴＦＴのトランジスタ特性を従来例と比較して示す図である。

【図６】従来例による選択核形成法を用いた薄膜トランジスタの工程断面図である。

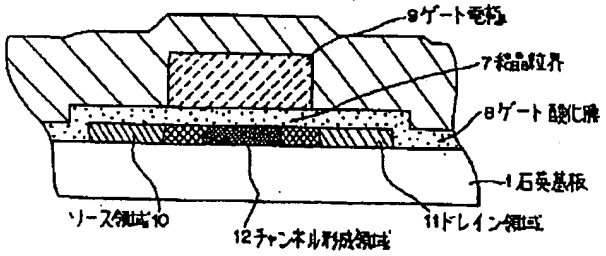
【符号の説明】

１　絶縁基板（石英基板）
２　非晶質シリコン
３　保護酸化膜
４　シリコン膜
５　照射領域（微結晶シリコン核）
６　固相成長したシリコン結晶粒
７　結晶粒界
８　ゲート酸化膜
９　ゲート電極
１０　ソース領域
１１　ドレイン領域
１２　チャンネル形成領域
１３　層間膜

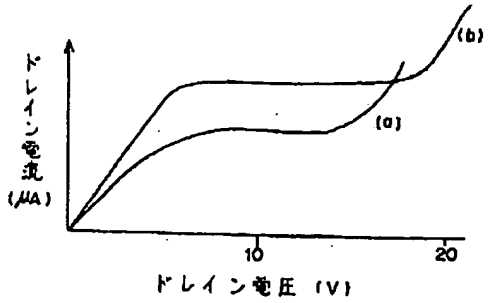
【図１】



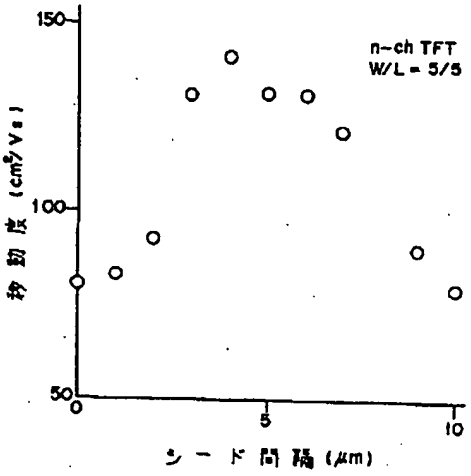
【図２】



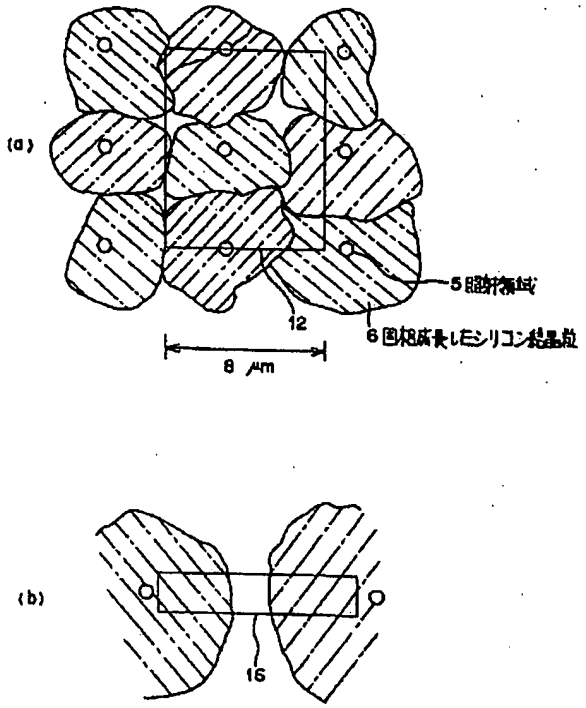
【図５】



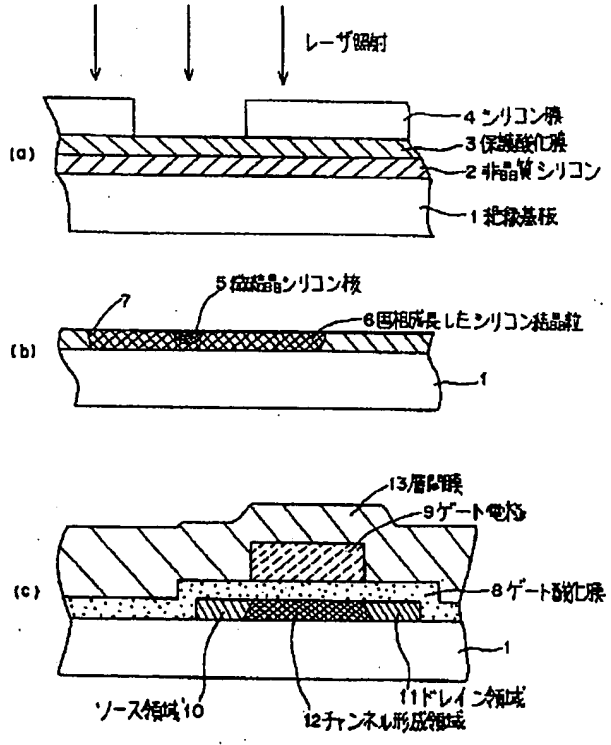
【図3】


150
100
50
0
5
10
n-ch TFT
W/L = 5/5
移動度 (cm²/Vs)
ゲート間隔 (μm)

【図4】


(a)
5 非結晶領域
12
6 固相成長したシリコン結晶粒
8 μm
(b)
16

【図6】


レーザ照射
(a)
4 シリコン膜
3 保護酸化膜
2 非晶質シリコン
1 絶縁基板
(b)
5 微結晶シリコン核
7
6 固相成長したシリコン結晶粒
1
(c)
13 層間膜
9 ゲート電極
8 ゲート酸化膜
1
ソース領域 10
12 チャンネル形成領域
11 ドレイン領域

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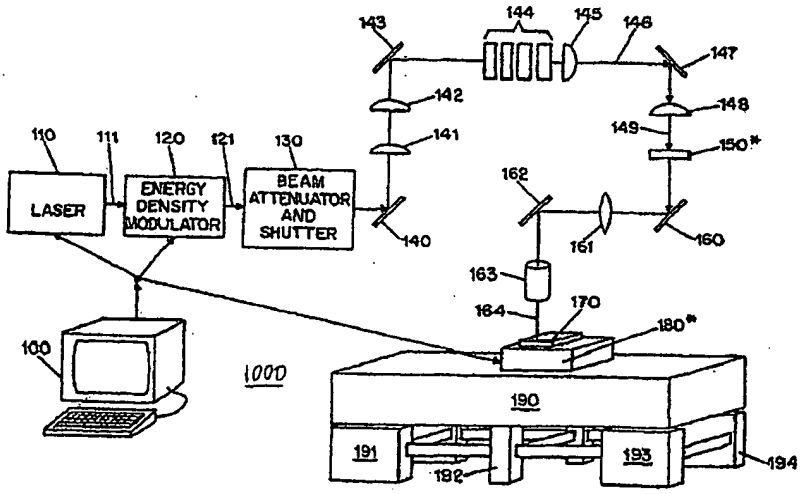
(54) Title: A SINGLE-SHOT SEMICONDUCTOR PROCESSING SYSTEM AND METHOD HAVING VARIOUS IRRADIATION PATTERNS



(57) Abstract: High throughput systems and processes for recrystallizing thin film semiconductors that have been deposited at low temperatures on a substrate are provided. A thin film semiconductor workpiece is irradiated with a laser beam to melt and recrystallize target areas of the surface exposed to the laser beam. The laser beam is shaped into one or more beamlets using patterning masks. The mask patterns have suitable dimensions and orientations to pattern the laser beam radiation so that the areas targeted by the beamlets have dimensions and orientations that are conducive to semiconductor recrystallization. The workpiece is mechanically translated along linear paths relative to the laser beam to process the entire surface of the work piece at high speeds. Position sensitive triggering of a laser can be used generate laser beam pulses to melt and recrystallize semiconductor material at precise locations on the surface of the workpiece while it is translated on a motorized stage.

WO 2004/017380 A2

A Single-Shot Semiconductor Processing System and Method Having Various Irradiation Patterns

SPECIFICATION

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from U.S. Patent Application No. 60/404,447, filed on August 19, 2002

BACKGROUND OF THE INVENTION

The present invention relates to semiconductor processing methods, and more particularly, to methods for making semiconductors materials in a form suitable for fabrication of thin-film transistor ("TFT") devices.

Flat panel displays and other display units are used as visual imaging interfaces for the common and ubiquitous electronic devices and appliances such as computers, image sensors, and television sets. The displays are fabricated, for example, from thin films of liquid crystal and semiconductor material placed on glass or plastic substrates. Each display is composed of a grid (or matrix) of picture elements ("pixels") in the liquid crystal layer. Thousands or millions of these pixels together create an image on the display. TFT devices fabricated in the semiconductor material layer are used as switches to individually turn each pixel "on" (light) or "off" (dark). The semiconductor materials used for making the TFTs, traditionally, are amorphous or polycrystalline silicon thin films. These films are deposited on to the substrates by physical or chemical processes at relatively low deposition temperatures in consideration of the low melting temperatures of the substrate materials used (e.g., glass or plastic). The relatively low deposition temperatures degrade the crystallinity of the deposited silicon films and cause them to be amorphous or polycrystalline.

Unfortunately, the device characteristics of a TFT fabricated in a silicon thin film undesirably degrade generally in proportion to the non-crystallinity of the silicon thin film. For industrial TFT device applications, silicon thin films of good crystalline quality are desirable. The crystallinity of a thin film of silicon deposited at low temperatures on a substrate may be advantageously improved by laser annealing. Maegawa et al. U.S. Patent 5,766,989, for example, describes the use

of excimer laser annealing ("ELA") to process amorphous silicon thin films deposited at low temperatures into polycrystalline silicon thin films for LCD applications. The conventional ELA processes, however, are not entirely satisfactory at least in part because the grain sizes in the annealed films are not sufficiently uniform for industrial use. The non-uniformity of grain size in the annealed films is related to the beam shape of the laser beam, which is used in the ELA process to scan the thin film.

Im et al. U. S. patent 6,573,531 and Im U.S. patent 6,322, 625 (hereinafter "the '531 patent" and "the '625 patent", respectively), both of which are incorporated by reference herein in their entireties, describe laser annealing apparatus and improved processes for making large grained polycrystalline or single crystal silicon structures. The laser annealing processes described in these patents involve controlled resolidification of target portions of a thin film that are melted by laser beam irradiation. The thin film may be a metal or semiconductor material (e.g., silicon). The fluence of a set of laser beam pulses incident on the silicon thin film is modulated to control the extent of melting of a target portion of a silicon thin film. Then, between the incident laser beam pulses, the position of the target portion is shifted by slight physical translation of the subject silicon thin film to encourage epitaxial lateral solidification. This so-called lateral solidification process advantageously propagates the crystal structure of the initially molten target portion into grains of large size. The apparatus used for the processing includes an excimer laser, beam fluence modulators, beam focussing optics, patterning masks, and a motorized translation stage for moving the subject thin film between or during the laser beam irradiation. (See e.g., the '531 patent, FIG. 1, which is reproduced herein).

Consideration is now being given to ways of further improving laser annealing processes for semiconductor thin films, and in particular for recrystallization of thin films. Attention is directed towards apparatus and process techniques, with a view to both improve the annealing process, and to increase apparatus throughput for use, for example, in production of flat panel displays.

SUMMARY OF THE INVENTION

The present invention provides systems and methods for recrystallizing amorphous or polycrystalline semiconductor thin films to improve their crystalline

quality and to thereby make them more suitable for device applications. The systems and processes are designed so that large surface area semiconductor thin films can be processed quickly.

Target areas of the semiconductor thin film may be intended for all or part semiconductor device structures. The target area may, for example, be intended for active regions of the semiconductor devices. The target areas are treated by laser beam irradiation to recrystallize them. The target areas are exposed to a laser beam having sufficient intensity or fluence to melt semiconductor material in the target areas. A one shot laser beam exposure may be used – the melted semiconductor material recrystallizes when the laser beam is turned off or moved away from the target area.

A large number of target areas in a region on the surface of the semiconductor thin film may be treated simultaneously by using laser radiation that is patterned. A projection mask can be deployed to suitably pattern the laser beam. The mask divides an incident laser beam into a number of beamlets that are incident on a corresponding number of target areas in a surface region of the semiconductor thin film. Each of the beamlets has sufficient fluence to melt the semiconductor material in target area on which it (beamlet) is incident. The dimensions of the beamlets may be chosen with consideration to the desired size of the target areas and the amount of semiconductor material that can be effectively recrystallized. Typical beamlet dimensions and corresponding target area dimensions may be of the order of the order of about 0.5 um to a few um.

An exemplary mask for patterning the laser beam radiation has a number of rectangular slits that are parallel to each other. Using this mask, an incident laser beam can be divided into a number of parallel beamlets. The target areas corresponding to these beamlets are distributed in the surface region in a similar parallel pattern. Another exemplary mask has a number of rectangular slits that are disposed in a rectangular pattern of sets of parallel and orthogonal slits. The slits may for example, be arranged in pairs along the sides of squares. Using this mask the resultant radiation beamlets and the corresponding target areas also are distributed in a similar rectangular pattern (e.g., in sets of parallel and orthogonal target areas).

The laser beam may be scanned or stepped across the surface of the semiconductor thin film to successively treat all regions of the surface with a repeating pattern of target areas. Conversely, the semiconductor thin film can be

moved relative to a laser beam of fixed orientation for the same purpose. In one embodiment of the invention, a motorized linear translation stage is used to move the semiconductor thin film relative to the laser beam in linear X-Y paths so that all surface regions of the semiconductor thin film can be exposed to the laser beam irradiation. The movement of the stage during the process can be continuous across a width of the semiconductor thin film or can be stepped from one region to the next. For some device applications, the target areas in one region may be contiguous to target areas in the next region so that extended strips of semiconductor material can be recrystallized. The recrystallization of contiguous target areas may benefit from sequential lateral solidification of the molten target areas. For other device applications, the target areas may be geometrically separate from target areas in the adjoining areas.

The generation of laser beam pulses for irradiation of the target areas may be synchronized with the movement of the linear translation stage so that the laser beam can be incident on designated target areas with geometric precision. The timing of the generated laser beam pulses may be indexed to the position of the translation stage, which supports the semiconductor thin film. The indexing may be occur in response to position sensors that indicate in real time the position of the stage, or may be based on computed co-ordinates of a geometrical grid overlaying the thin film semiconductor.

BRIEF DESCRIPTION OF THE DRAWINGS

Further features of the invention, its nature, and various advantages will be more apparent from the following detailed description of the preferred embodiments and the accompanying drawings, wherein like reference characters represent like elements throughout, and in which:

FIG. 1 is a schematic and block diagram of a semiconductor processing system for the laser annealing of semiconductor thin films for recrystallization;

FIG. 2 is a top exploded view of an exemplary thin film silicon workpiece;

FIGS. 3a and 3b are top views of exemplary masks in accordance with the principles of present invention;

FIG. 4 is a schematic diagram illustrating a portion of the thin film silicon workpiece of FIG. 2 that has been processed using the mask of FIG. 3a, in accordance with the principles present invention;

FIG. 5 is a schematic diagram illustrating an exemplary processed thin film silicon workpiece that has been processed using the mask of FIG. 3b in accordance with the principles present invention; and

FIG. 6 is a schematic diagram illustrating an exemplary geometrical pattern whose co-ordinates are used to trigger radiation pulses incident on a silicon thin film workpiece in accordance with the principles present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention provides processes and systems for recrystallization of semiconductor thin films by laser annealing. The processes for recrystallization of semiconductor thin films involve one–shot irradiation of regions of a semiconductor thin film workpiece to a laser beam. The systems direct a laser beam to a region or spot on the surface of the semiconductor thin film. The incident laser beam has sufficient intensity or fluence to melt targeted portions of the region or spot of the semiconductor thin film on which the laser beam is incident. After the targeted incident areas or portions are melted, the laser beam is moved or stepped to another region or spot on the semiconductor thin film. The molten semiconductor material recrystallizes when the incident laser beam is moved away. The dwell time of the laser beam on a spot on the semiconductor thin film may be sufficient small so that the recrystallization of an entire semiconductor thin film workpiece can be carried out quickly with high throughput rates.

In order that the invention herein described can be fully understood the subsequent description is set forth in the context of laser annealing of silicon thin films. The annealed silicon thin films may be intended for exemplary TFT device applications. It will, however, be understood that the invention is equally applicable to other types of materials and/or other types of device applications.

An embodiment of the present invention is described herein with reference to FIGS. 1-6. Thin film silicon workpieces (see e.g., workpiece 170, FIGS. 2 and 4-6) are used herein as illustrative workpieces. Workpiece 170 may, for example, be a film of amorphous or randomly grained polycrystalline silicon

deposited on a glass or plastic substrate for use in a flat panel display. The silicon film thickness may, for example, be in the range of about 100 Angstroms to greater than about 5000 Angstroms. Further, the present invention is described in the context of laser annealing apparatus 1000 shown in FIG. 1, which is disclosed in the '531 patent incorporated by reference herein. The processes of the present invention are described using this apparatus only for purposes of illustration, with the understanding that the principles of the present invention are applicable to any other irradiation apparatus or system that may be available.

Apparatus 1000 includes a radiation source 110 capable of generating an energetic radiation beam, suitable optical components 120-163 for shaping and directing the radiation beam to the surface of a work piece, and a motorized translation stage assembly 180 for supporting workpiece 170 during the processing. Radiation source 110 may be any suitable radiation source that is capable of generating continuous or pulsed beams of radiant energy of sufficient intensity to melt incident areas or portions of the semiconductor thin film of workpiece 170. Radiation source 110 may, for example, be any suitable solid state or other type of laser, an electron beam or ion beam source. For many semiconductor recrystallization applications, the radiation beam generated by radiation source 110 may have an intensity in the range of about 10 mJ/cm2 to 1J/cm2 (e.g., 500mJ/cm2). Suitable optics and/or electronics may be used to modulate or pulse the radiation beam generated by radiation source 110. A pulse duration (FWHM) in the range of about 10 to about 200 nsec, and a pulse repetition rate in the range of about 10 Hz to about 200 Hz may, for example, be suitable for laser annealing of silicon thin film workpieces 170. A suitable radiation source 110 for laser annealing of silicon thin film workpieces 170 may, for example, be a commercially available XeCl pulsed excimer laser (e.g., a Model LPX-315I excimer laser sold by Lambda Physik USA, Inc. of 3201 West Commercial Blvd. Ft. Lauderdale, FL 33309, USA).

Suitable optics 120-163 may be used to modulate, collimate or focus the radiation beam generated by laser 110 on to workpiece 170. In particular, an energy density modulator 120 may be used to time laser beam pulses and/or to modulate their fluence. Modulator 120 may, for example, be a commercially available controllable beam energy density modulator (e.g., a MicroLas® two-plate variable-attenuator also sold by Lambda Physik USA, Inc). Other optical components for shaping the laser beam (e.g., steering mirrors 140, 143, 147, 160 and 162,

expanding and collimating lenses 141 and 142, homogenizer 144, condenser lens 145, a field lens 148, eye piece 161, controllable shutter 152, multi-element objective lens 163), also may, for example, be any suitable commercially available optical components sold by the by Lambda Physik USA, or by other vendors.

The suitable optical components 120-163 for shaping and directing the radiation beam may include a masking system 150. Masking system 150 may be a projection masking system, which is used for patterning incident radiation (149) so that radiation beam (164) that is ultimately incident on workpiece 170 is geometrically shaped or patterned.

Stage assembly 180, on which workpiece 170 rests during processing, may be any suitable motorized translation stage capable of movement in one or more dimensions. A translation stage capable of high translation speeds may be advantageous for the high throughput single –shot processing described herein. Stage assembly 180 may be supported on suitable support structures to isolate the thin film silicon workpiece 170 from vibrations. The support structures may, for example, include conventional optical benches such as a granite block optical bench 190 mounted on a vibration isolation and self-leveling system 191, 192, 193 and 194.

A computer 100 may be linked to laser 110, modulator 120, stage assembly 180 and other controllable components of apparatus 1000. Computer 100 may be used to control the timing and fluence of the incident laser beam pulses and the relative movement of the stage assembly 180. Computer 100 may be programmed to controllably move stage assembly translation stage 180 in X, Y and Z directions. Workpiece 170 may be moved, for example, over predetermined distances in the X-Y plane and as well as in the Z direction in response to instruction from computer 1000. In operation, the position of workpiece 170 relative to the incident radiation beam 164 may be continuously adjusted or intermittently reset during the single-shot laser annealing process at suitable times according to preprogrammed process recipes for single shot recrystallization of workpiece 170. The movement of workpiece 170 may be synchronized or co-ordinated with the timing of radiation beam pulses generated by laser 100.

In apparatus 1000, the movement of stage assembly 180 translates the workpiece 170 and the radiation beam (164) relative to each other. In the processing described herein the radiation beam (164) is held fixed in a position or orientation while stage 180 is moved. Alternative configurations or arrangements of optical

components may be used to move incident radiation beam 164 and workpiece 170 relative to each other along defined paths. For example, a computer-controlled beam steering mirror may be used to deflect radiation beam 164 while stage 180 is held fixed in position. By such beam deflecting arrangements it may be possible to completely or partially dispense with the use of mechanical projection masks (e.g., masking system 150) and instead use electronic or optical beam guiding mechanisms to scan or step selected portions of workpiece 170 at a rapid pace.

Using apparatus 1000, sequential lateral solidification of molten semiconductor material may be achieved using, for example, the processes that involve incremental movement or shifting the position of stage 180 between excimer laser pulses as described in the '531 patent. The movements of stage 170 are small, so that the portions of the silicon thin film that are molten by sequential pulses are proximate to each other. The proximity of the two molten portions allows the first portion to recrystallize and propagate its crystal structure into the adjacent portion, which is melted by the next pulse.

In the single shot recrystallization processes described here, apparatus 1000 may be used to scan or step a laser beam across the surface of a semiconductor thin film by moving of stage assembly 180. The laser beam has sufficient intensity or fluence to melt target areas in the regions or spots at which the laser beam pulses are incident. To process an entire workpiece 170, stage assembly 180 may be moved predetermined distances to cause the laser beam to move along paths across semiconductor thin film 175/workpiece 170. FIG. 2 also schematically shows paths 230, 255 etc. that may be traced by incident radiation beam 164 as it is moved across the surface of the workpiece 170.

The number of paths and their geometrical orientation may be determined by the cross sectional dimensions of the laser beam and the target area requirements of the circuit or device applications for which workpiece 170 is being processed. Accordingly, the surface of a semiconductor thin film 175/workpiece 170 may be partitioned in a geometric array of regions for generating processing recipes for computer 1000 or otherwise controlling the operation of apparatus 1000. FIG. 2 shows an exemplary geometrical partitioning of the surface of a semiconductor thin film 175 on workpiece 170. In the exemplary geometrical partitioning shown in FIG. 2, the surface is divided into a number of rows (e.g., 205, 206, 207, etc.) each having a width W. The widths of rows W may be selected with consideration to the cross

sectional width of incident radiation beam 164. Each row contains one or more regions. As an illustrative numerical example, workpiece 170 may have x and y dimensions of about 30 cms and 40 cms, respectively. Each of rows 205, 206, 207, . . . etc., may, for example, have a width W of about ½ cm in the Y direction. This value of W may, for example, correspond a laser beam width of about the same size. Thus, the surface of workpiece 170 can be divided into eighty (80) rows each with a length of about 30 cms in the X direction. Each row contains one or more regions whose combined length equals 30 cms (not shown).

The co-ordinates of each row may be stored in computer 100 for use by the processing recipes. Computer 1000 may use the stored co-ordinates, for example, to compute the direction, timing and travel distances of stage 180 during the processing. The co-ordinates also may be used, for example, to time the firing of laser 110 so that designated regions of semiconductor thin film 175 are irradiated as stage 180 is moved.

Workpiece 170 may be translated in linear directions while silicon thin film 175 is being irradiated so that a linear strip of silicon thin film 175 is exposed to radiation beams of melting intensity or fluence. The translation paths traced by the radiation beams may be configured so that the desired portions of the entire surface of thin film silicon 175 are successively treated by exposure to laser beams. The translation paths may be configured, for example, so that the laser beam traverses rows 205, 206, 207, etc. sequentially. In FIG. 2, the radiation beam is initially directed to a point 220 off side 210' near the left end of row 205. Path 230 represents, for example, the translation path traced by the center of the radiation beam through row 205 as stage 180 is moved in the negative X direction.

The movement of stage 180 may be conducted in a series of steps in an intermittent stop-and-go fashion, or continuously without pause until the center of the radiation beam is directed to a point 240 near the right end of row 205. Path segments 225 and 235 represent extensions of path 230 that may extend beyond edges 210' and 210'' of workpiece 170 to points 220 and 240, respectively. These segments may be necessary to accommodate acceleration and deceleration of stage assembly 180 at the ends of path 230 and/or may be useful for reinitializing stage 180 position for moving stage 180 in another direction. Stage 180 may, for example, be moved in the negative Y direction from point 240, so that the center of the radiation beam traces path 245 to point 247 next to the right end of row 206 in preparation for treating the silicon

material in row 206. From point 247 in manner similar to the movement along path 230 in row 205 (but in the opposite direction), stage 180 is moved in the X direction so that the center of the radiation beam moves along path 255 irradiating thin film silicon material in row 206. The movement may be continued till the center of radiation beam is incident at spot 265 that is near the left end of row 206. Path extensions 260 and 250 represent segments of path 255 that may extend beyond edges 210' and 210'' to spots 247 and 265, respectively. Further linear movement of stage 180 in the Y direction moves the center of the incident radiation beam along path 270 to a point 272 next to row 207. Then, the thin film silicon material in row 207 may be processed by moving stage 180 in the negative X direction along path 275 and further toward the opposite side 210"of workpiece 170. By continuing X and Y direction movements of stage 180 in the manner described for rows 205, 206, and 207, all of the rows on the surface of thin film silicon 175 may be treated or irradiated. It will be understood that the particular directions or sequence of paths described above are used only for purposes of illustration, other directions or sequences may be used as appropriate.

In an operation of apparatus 1000, silicon thin film 175 may be irradiated by beam pulse 164 whose geometrical profile is defined by masking system 150. Masking system 150 may include suitable projection masks for this purpose. Masking system 150 may cause a single incident radiation beam (e.g., beam 149) incident on it to dissemble into a plurality of beamlets in a geometrical pattern. The beamlets irradiate a corresponding geometrical pattern of target areas in a region on the thin film silicon workpiece. The intensity of each of the beamlets may be chosen to be sufficient to induce complete melting of irradiated thin film silicon portions throughout their (film) thickness.

The projection masks may be made of suitable materials that block passage of radiation through undesired cross sectional areas of beam 149 but allow passage through desired areas. An exemplary projection mask may have a blocking/unblocking pattern of rectangular stripes or other suitable geometrical shapes which may be arranged in random or in geometrical patterens. The stripes may, for example, be placed in a parallel pattern as shown in FIG. 3a, or in a mixed parallel and orthogonal pattern as shown in FIG. 3b, or any other suitable pattern.

With reference to FIG. 3a, exemplary mask 300A includes beam-blocking portions 310 which has a number of open or transparent slits 301, 302, 303,

etc. Beam-blocking portions 310 prevent passage of incident portions of incident beam 149 through mask 300A. In contrast, open or transparent slits 301, 302, 303, etc. permit passage of incident portions of radiation beam 149 through mask 300. Accordingly, radiation beam 164 exiting mask 300A has a cross section with a geometrical pattern corresponding to the parallel pattern of the plurality of open or transparent slits 301, 302, 303, etc. Thus when positioned in masking system 150, mask 300A may be used to pattern radiation beam 164 that is incident on semiconductor thin film 175 as a collection of parallel rectangular-shaped beamlets. The beamlets irradiate a corresponding pattern of rectangular target areas in a region on the surface of the on semiconductor thin film 175. The beamlet dimensions may be selected with a view to promote recrystallization or lateral solidification of thin film silicon areas melted by a beamlet. For example, a side length of a beamlet may be chosen so that corresponding target areas in adjoining regions are contiguous. The size of the beamlets and the inter beamlet separation distances may be selected by suitable choice of the size and separation of transparent slits 301, 302, 303, etc. Open or transparent slits 301, 302, 303, etc. having linear dimensions of the order of a micron or larger may, for example, generate laser radiation beamlets having dimensions that are suitable for recrystallization processing of silicon thin films in many instances.

FIG. 3b shows another exemplary mask 300B with a pattern which is different than that of mask 300A. In mask 300B, a number of open or transparent slits 351, 352, 361, 362 etc. may, for example, be arranged in pairs along the sides of squares. This mask 300B also may be used in masking system 150 to pattern the radiation beam 164 that is incident on semiconductor thin film 175. The radiation beam 164 may be patterned, for example, as a collection of beamlets arranged in square-shaped patterns. The beamlet dimensions may be selected with a view to promote recrystallization or lateral solidification of thin film silicon areas melted by a beamlet. Open or transparent slits 351, 352, 361, 362, etc. having linear dimensions of about 0.5 micron may generate laser radiation beamlets of suitable dimensions for recrystallization of thin film silicon areas

It will be understood that the specific mask patterns shown in FIGS. 3a and 3b are exemplary. Any other suitable mask patterns may be used including, for example, the chevron shaped patterns described in the '625 patent. A particular mask pattern may be chosen in consideration of the desired placement of TFTs or other

circuit or device elements in the semiconductor product for which the recrystallized thin film silicon material is intended.

FIG. 4 shows, for example, portions of workpiece 170 that has been processed using mask 300A of FIG. 3a. (Mask 300A may be rotated by about 90 degrees from the orientation shown in FIG. 3a). The portion shown corresponds to a row, for example, row 205 of workpiece 170 (FIG. 2). Row 205 of processed workpiece 170 includes recrystallized polycrystalline silicon linear regions or strips 401, 402, etc. Each of the linear strips is a result of irradiation by a radiation beamlet formed by a corresponding mask slit 301, 302, etc. The continuous extent of recrystallized silicon in the linear strips across row 205 may be a consequence, for example, of a continuous movement of the stage 180 along path 230 under laser beam exposure (FIG. 2). Strips 401, 402, may have a microstructure corresponding to the one shot exposure with colliding liquid/solid growth fronts in the center creating a long location-controlled grain boundary. Alternatively, in a directional solidification process the continuous extent may be a result of closely spaced stepped movements of stage 180 along path 230 that are sufficiently overlapping to permit formation of a continuous recrystallized silicon strip. In this alternative process, the microstructure of the recrystallized material may have long grains parallel to the scanning direction. The recrystallized polycrystalline silicon (e.g. strips 401, 402, etc.) may have a generally uniform structure, which may be suitable for placement of the active region of one or more TFT devices. Similarly, FIG. 5 shows, exemplary results using mask 300B of FIG. 3b. Exemplary processed workpiece 170 includes recrystallized polycrystalline silicon strips 501, 502, etc. Recrystallized polycrystalline silicon strips 501, 502, etc. like strips 401 and 402 may have a uniform crystalline structure, which is suitable for placement of the active regions of TFT devices. Strips 501 and 502 that are shown to be generally at right angles to each other may correspond to radiation beamlets formed by orthogonal mask slits (e.g., FIG. 3b slits 351, 361). The distinct geometrical orientation and physical separation of strips 501 and 502 (in contrast to extended length of strips 401 and 402) may be a consequence, for example, of physically separated exposure to laser radiation during the processing of workpiece 170. The separated radiation exposure may be achieved by stepped movement of stage 180 (e.g., along path 230 FIG. 2) during the processing. Additionally or alternatively, the separated exposure may be achieved by triggering laser 110 to generate radiation pulses at appropriate times and positions of stage 180 along path

230 while stage 180 and laser beam 164 are moved or scanned relative to each other at constant speeds.

Computer 100 may be used control the triggering of laser 110 at appropriate times and positions during the movement of stage 180. Computer 100 may act according to preprogrammed processing recipes that, for example, include geometrical design information for a workpiece-in-process. FIG. 6 shows an exemplary design pattern 600 that may be used by computer 1000 to trigger laser 110 at appropriate times. Pattern 600 may be a geometrical grid covering thin film silicon 175/workpiece 170. The grid may, for example, be a rectangular x-y grid having co-ordinates (x1, x2, . . . etc.) and (y1, y2, . . . etc.). The grid spacings may be regular or irregular by design. Pattern 600 may be laid out as physical fiducial marks (e.g., on the thin film silicon workpiece) or may be a mathematical construct in the processing recipes. Computer 100 may trigger laser 110 when stage 180 is at the grid co-ordinates (xi, yi). Computer 100 may do so in response, for example, to conventional position sensors or indicators, which may be deployed to sense the position of stage 180. Alternatively, computer 100 may trigger laser 110 at computed times, which are computed from parameters such as an initial stage position, and the speeds and direction of stage movements from the initial stage position. Computer 100 also may be used advantageously to instruct laser 110 to emit radiation pulses at a variable rate, rather than at a usual even rate. The variable rate of pulse generation may be used beneficially to accommodate changes in the speed of stage 180, for example, as it accelerates or decelerates at the ends of paths 230 and the like.

It will be understood that the foregoing is only illustrative of the principles of the invention and that various modifications can be made by those skilled in the art without departing from the scope and spirit of the invention, which is limited only by the claims that follow.

CLAIMS:

1. A method for recrystallizing a semiconductor thin film to improve its crystalline quality, comprising the steps of:

(a) irradiating a first region of a surface of the semiconductor thin film with a pulse of a radiation beam, wherein the radiation beam is first patterned into at least one beamlet in a pattern of beamlets, wherein each beamlet is incident on a target area in the first region, wherein each beamlet has sufficient fluence to melt semiconductor material in the target area on which it is incident, and wherein the molten semiconductor material in the target area recrystallizes when it is no longer exposed to the incident beamlet; and

(b) continuously translating the semiconductor thin film relative to the radiation beam so that a next region of the surface of the semiconductor thin film is irradiated in the same manner as step (a).

2. The method of claim 1, wherein the beamlets have cross sectional dimensions of the order of a micron.

3. The method of claim 1 further comprising the step of using a mask to pattern the beamlets from the radiation beam pulse.

4. The method of claim 3, wherein the mask comprises:

a blocking portion that blocks through passage of radiation incident on it;

a plurality of slits in a pattern, wherein the slits allow through passage of radiation incident on them, and wherein the slits are disposed substantially parallel to each other in the pattern.

5. The method of claim 3, wherein the mask comprises:

a blocking portion that blocks through passage of radiation incident on it;

a plurality of slits in a pattern, wherein the slits allow through passage of radiation incident on them, and wherein the slits are arranged in pairs along the sides of rectangles in the pattern.

6. The method of claim 1, further the step of comprising supporting the

semiconductor thin film on a movable stage, and wherein translating the semiconductor thin film relative to the radiation beam comprises moving the movable stage along a linear path to the next region.

7. The method of claim 6, wherein the semiconductor thin film comprises rows of regions, further comprising moving the movable stage along the linear path through a first row of regions on the surface of the semiconductor thin film.

8. The method of claim 7 wherein the movable stage is moved continuously without pause through the row of regions.

9. The method of claim 7 wherein the movable stage is paused at a region and is then stepped to an adjacent region.

10. The method of claim 7 further comprising moving the movable stage along linear paths through successive rows of regions until the entire surface of the semiconductor thin film has been processed.

11. The method of claim 1 wherein at least one of the target areas in the first region is contiguous to a corresponding target area in the next region, so that after irradiation of the first and next regions an extended strip or recrystallized semiconductor material is formed.

12. A method for recrystallizing a semiconductor thin film to improve its crystalline quality, comprising the steps of :

(a) using a laser to generate a pulse of a radiation beam;

(b) irradiating a first region of a surface of the semiconductor thin film with the pulse of the radiation beam, wherein the radiation beam is first patterned into at least one beamlet in a pattern of beamlets, wherein each beamlet is incident on a target area in the first region, wherein each beamlet has sufficient fluence to melt semiconductor material in the target area on which it is incident, and wherein the molten semiconductor material in the target area recrystallizes when it is no longer exposed to the incident beamlet; and

(c) after irradiating the first region of the surface of the semiconductor thin film with the pulse of the radiation beam, translating the semiconductor thin film relative to the radiation beam so that a next region of the surface of the semiconductor thin film is irradiated in the manner of steps (a) and (b).

13. The method of claim 12, wherein the laser is triggered to generate the pulse of the radiation beam according to the position of the thin film semiconductor region relative to the radiation beam.

14. The method of claim 12, further comprising supporting the semiconductor thin film on a movable stage, and wherein translating the semiconductor thin film relative to the radiation beam comprises moving the movable stage, and wherein the laser is triggered to generate the pulse of the radiation beam according to the position of the movable stage.

15. The method of claim 14, wherein the position of the movable stage is sensed by position sensors.

16. The method of claim 14, wherein the position of the movable stage is computed from an initial position of the stage.

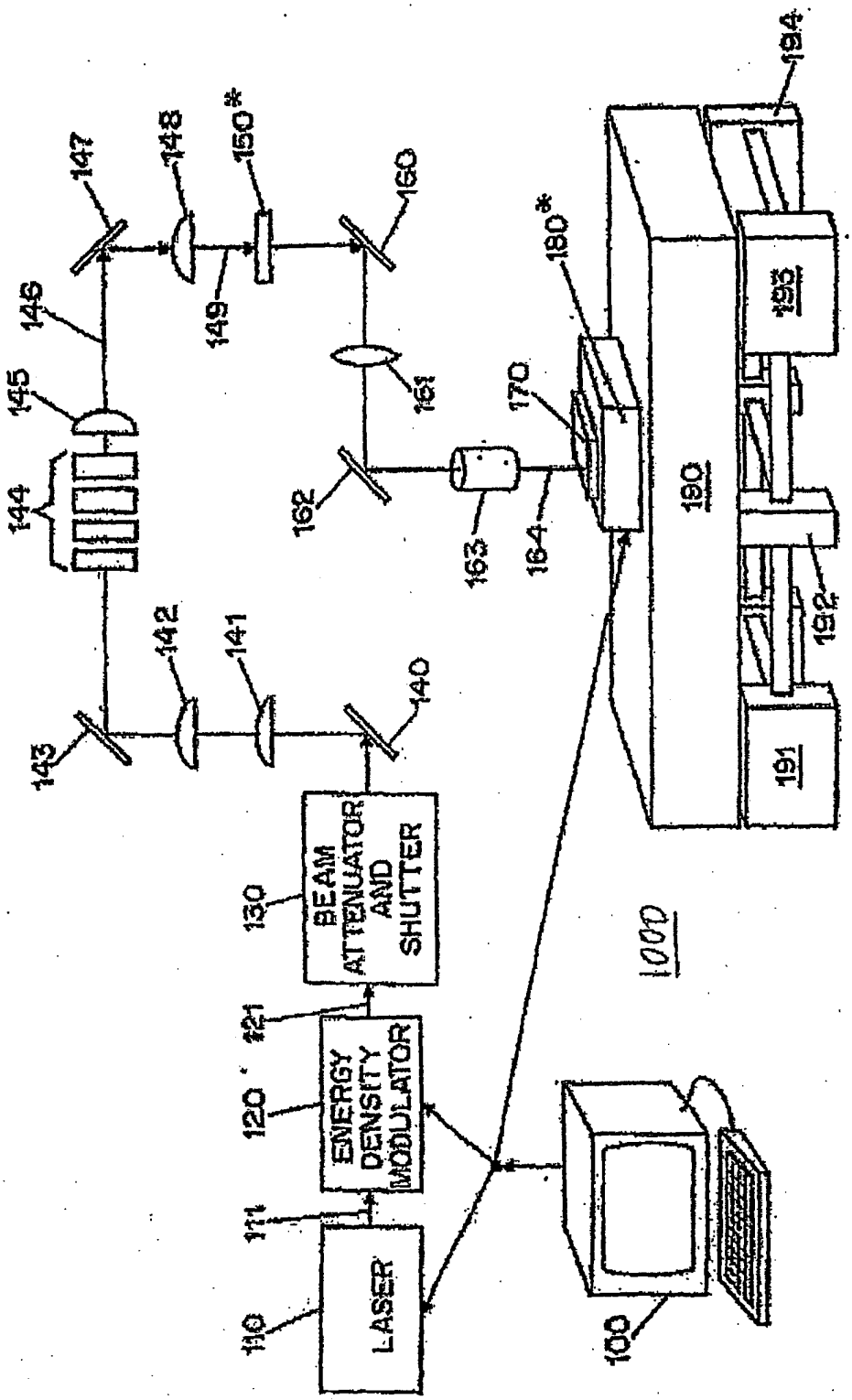
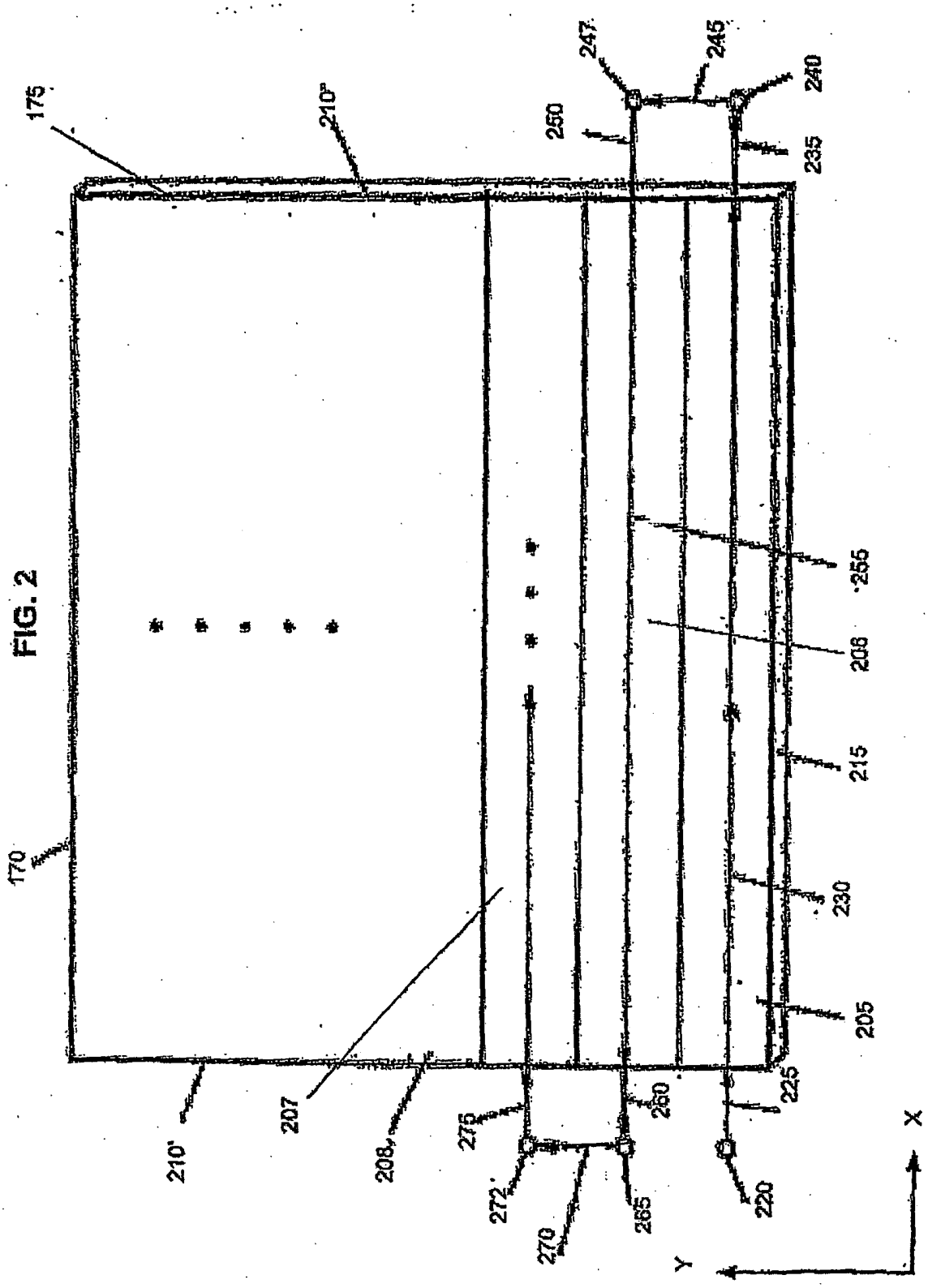


FIG. 1 (Prior Art)

FIG. 2


175
210"
247
245
240
260
235
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215
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205
225
170
210'
207
208
275
260
220
272
270
265
X
Y

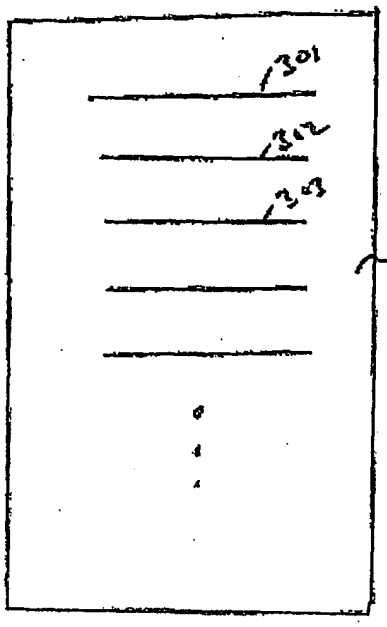

Fig 3a.

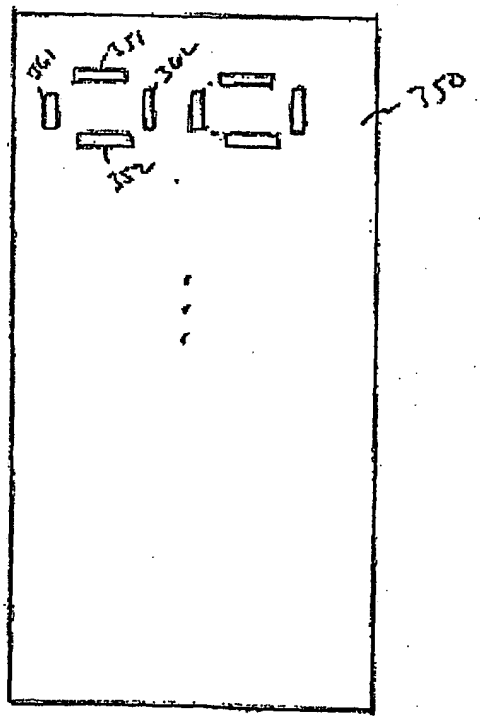

Fig 3b

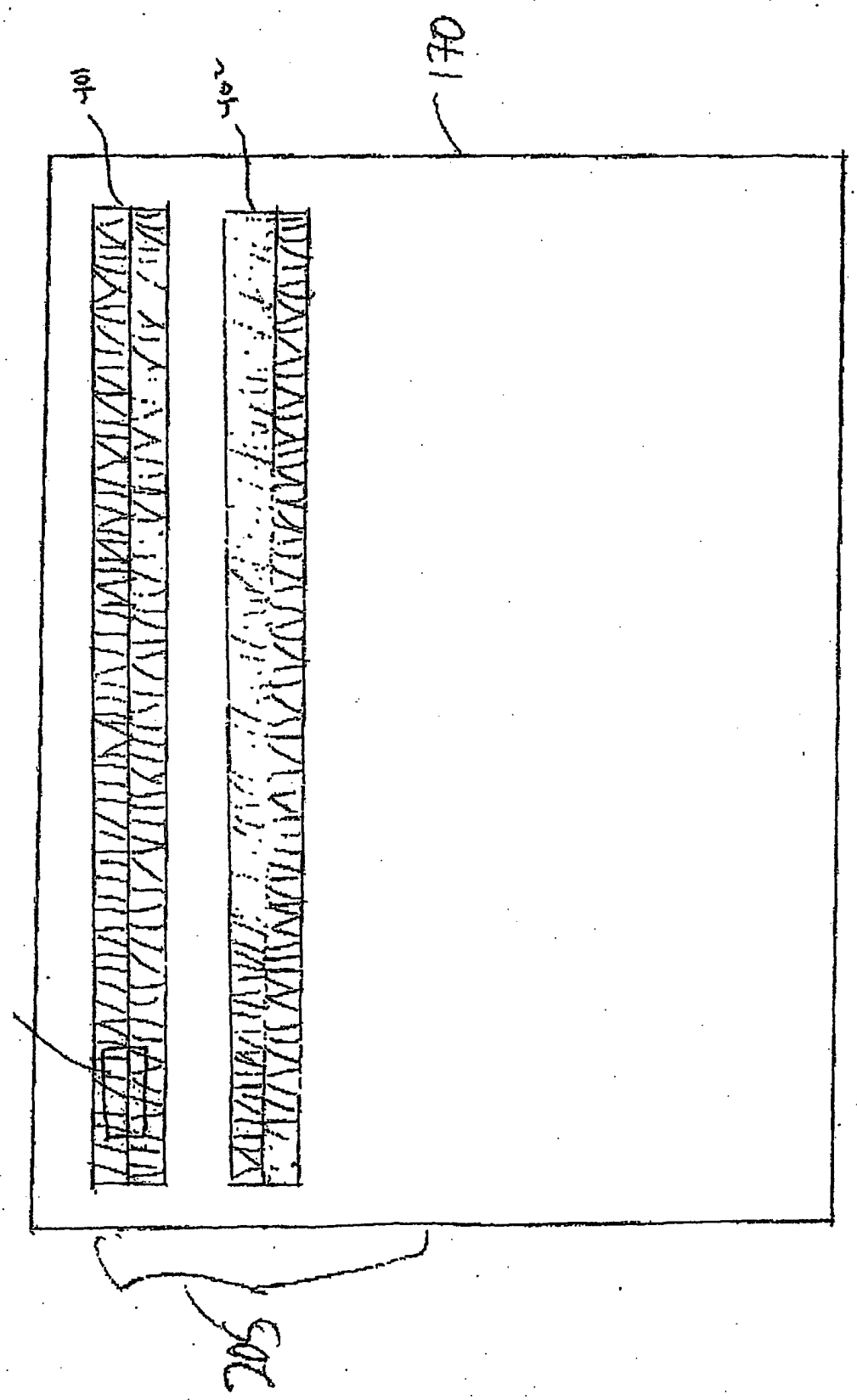

Fig 4

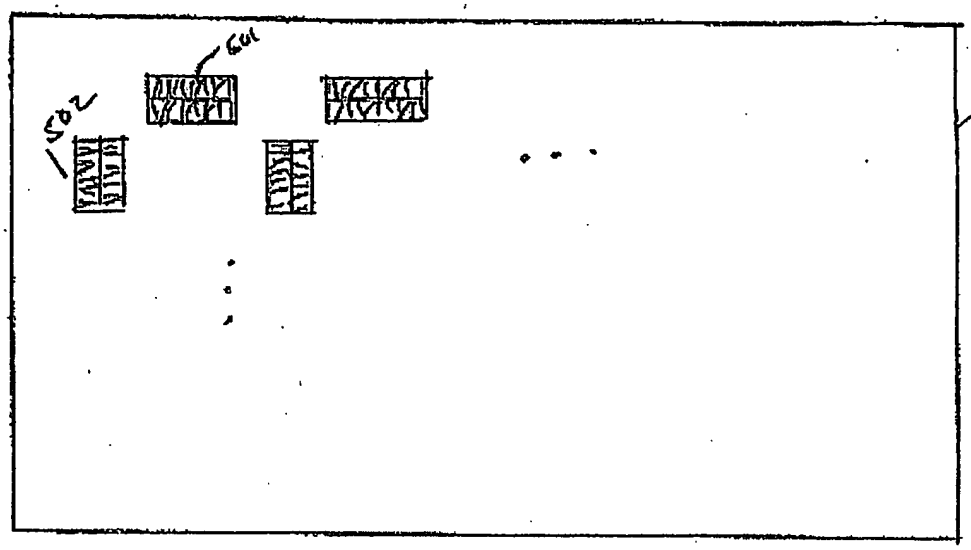

Fig 5

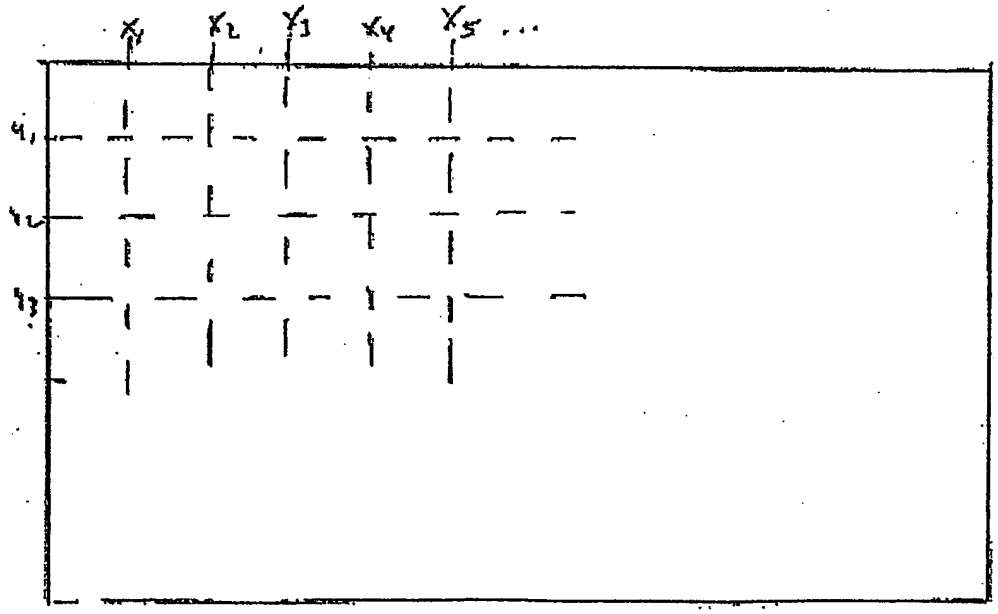

Fig 6

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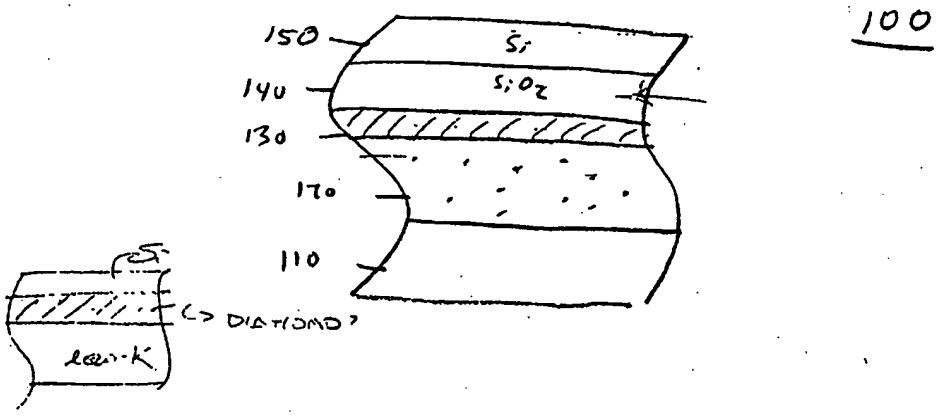
(54) Title: SPECIALIZED SUBSTRATES FOR USE IN SEQUENTIAL LATERAL SOLIDIFICATION PROCESSING



(57) Abstract: Substrates having modified effective thermal conductivity for use in the sequential lateral solidification process are disclosed. In one arrangement, a substrate includes a glass base layer, a low conductivity layer formed adjacent to a surface of the base layer, a high conductivity layer formed adjacent to the low conductivity layer, a silicon compound layer formed adjacent to the high conductivity layer, and a silicon layer formed on the silicon compound layer. In an alternative arrangement, the substrate includes an internal subsurface melting layer which will act as a heat reservoir during subsequent sequential lateral solidification processing.

WO 03/046965 A1

SPECIALIZED SUBSTRATES FOR USE IN SEQUENTIAL LATERAL SOLIDIFICATION PROCESSING

SPECIFICATION

BACKGROUND OF THE INVENTION

I. Field of the invention.

The present invention relates to techniques for processing of semiconductor films, and more particularly to techniques for processing semiconductor films on glass or other substrates.

II. Description of the related art.

Techniques for fabricating large grained single crystal or polycrystalline silicon thin films using sequential lateral solidification are known in the art. For example, in U.S. Patent Application Serial No. 09/390,537, the contents of which are incorporated by reference herein and which application is assigned to the common assignee of the present application, particularly advantageous apparatus and methods for growing large grained polycrystalline or single crystal silicon structures using energy-controllable laser pulses and small-scale translation of a silicon sample to implement sequential lateral solidification are disclosed. Using the sequential lateral solidification technique, low defect density crystalline silicon films can be produced on those substrates that do not permit epitaxial regrowth, upon which high performance microelectronic devices can be fabricated.

The effectiveness with which sequential lateral solidification can be implemented depends on several factors, the most important of which corresponds to the length of lateral crystal growth achieved per laser pulse. Such lateral crystal growth depends on several parameters, including the duration of the laser pulses, film thickness, substrate temperature at the point of laser pulse irradiation, the energy density of the laser pulse incident on the substrate, and the effective thermal conductivity of the substrate.

In particular, if all other factors are kept constant, reducing the thermal conductivity of the substrate will have the effect of increasing lateral crystal growth.

While there have been attempts to utilize low thermal conductivity materials, such as porous glass, in connection with sequential lateral solidification for the purpose of enhancing lateral crystal growth, such attempts have not achieved commercially viable results. For example, when a porous glass layer is used under a silicon film in the sequential lateral solidification process densification, and subsequent physical distortion, of such glass has been observed. Accordingly, there exists a need in the art for a technique for fabricating substrates having a modified effective thermal conductivity in order to optimize the sequential lateral solidification process.

SUMMARY OF THE INVENTION

An object of the present invention is to provide substrates having modified effective thermal conductivity which can be later used in an optimized sequential lateral solidification process.

A further object of the present invention is to provide substrates having modified effective thermal conductivity.

Still a further object of the present invention is to provide substrates having a directionally optimized effective thermal conductivity.

Yet a further object of the present invention is to provide multi layer substrates where one or more of the subsurface layers act as a heat reservoir in order to optimize the effective thermal characteristics of the substrate.

In order to achieve these objectives as well as others that will become apparent with reference to the following specification, the present invention provides a substrate having modified effective thermal conductivity for use in the sequential lateral solidification process. The substrate includes a base layer, e.g., glass, a low conductivity layer formed adjacent to a surface of the base layer, a high conductivity layer formed adjacent to the low conductivity layer, and a silicon layer formed on the high conductivity layer.

In a preferred arrangement, the low conductivity layer is porous glass, and is in the range of 5,000 Angstroms to 2 microns thick. The high conductivity layer may

be a metal, and should be sufficiently thin so as to not increase the overall vertical conductivity of the substrate, preferably in the range of 50 to 5,000 Angstroms thick.

An intermediate silicon compound layer is preferably formed between the silicon layer and the high conductivity layer. The silicon compound may be silicon dioxide, and should be sufficiently thick to prevent diffusion of impurities from the high conductivity layer. It is preferred that the silicon compound layer is in the range of 200 to 2,000 Angstroms thick.

In an alternative arrangement, the present invention provides a substrate having modified effective thermal conductivity for use in the sequential lateral solidification process, wherein the high conductivity layer is replaced by an internal subsurface melting layer. In this arrangement, the substrate includes a base layer, a low conductivity layer formed adjacent to the base layer, a subsurface melting layer having a melting point which is less than that of silicon and formed adjacent to the low conductivity layer, a silicon compound layer formed adjacent to the subsurface melting layer, and silicon layer formed on the silicon compound layer.

The accompanying drawings, which are incorporated and constitute part of this disclosure, illustrate a preferred embodiment of the invention and serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic diagram of a substrate in accordance with a preferred embodiment of the present invention;

Fig. 2 is an illustrative diagram showing lateral solidification of silicon;

Figs. 3a and b are graphs showing the relationship between the temperature of solidifying silicon and the position of such silicon around a liquid to solid interface; and

Fig. 4 is a schematic diagram of a substrate in accordance with a second preferred embodiment of the present invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to Fig. 1, a preferred embodiment of the present invention will be described. As shown in Fig. 1, the substrate 100 includes a bulk glass plate layer 110, a low conductivity layer 120, a high conductivity layer 130, a silicon dioxide layer 130 and a semiconducting film layer 150. The multilayer structure of substrate 100 may be fabricated by any combination of thin film formation techniques, such as physical or chemical vapor deposition, electrochemical deposition, or spin coating.

The low conductivity layer 120 may be porous glass or a polymer film layer. In addition, the layer 120 must have a conductivity which is less than the glass plate 110 and sufficiently thick so that the glass plate layer 110 will not participate when the substrate 100 is used in later processing. Layer 120 will be in the order of 5,000 Angstroms to 2 microns thick.

The high conductivity layer 130 may be a metallic layer such as copper or aluminum. The high conductivity layer must have a conductivity which is greater than that of the glass plate 110, and sufficiently thin so as to not increase the overall vertical conductivity of the substrate 100, i.e., conductivity in the direction which crosses layers 110, 120, 130, 140, 150. Typically, layer 130 will be in the order of 50 to 5,000 Angstroms thick.

The silicon dioxide layer 140 should be sufficiently thick to prevent potential diffusion of unwanted impurities from the underlying layer 130 to the silicon cap 150. The Layer 140 will be in the order of 200 to 2,000 Angstroms thick. Alternatively, the layer 140 may be fabricated from silicon nitride or a mixture of silicon dioxide and silicon nitride.

Alternatively, the high conductivity layer 130 may be formed from a material which is electrically and chemically compatible with the semiconducting film layer 150, such as diamond. In this case, the silicon dioxide layer 140 may be omitted, with the semiconducting film layer 150 formed directly on the high conductivity layer 130.

Finally, the top semiconducting film layer may be either be amorphous, microcrystalline or polycrystalline silicon, or a mixture thereof. Typically, layer 150 will be in the order of 200 to 2,000 Angstroms thick.

When fabricated as described above, the substrate 100 will exhibit either a reduced overall effective thermal conductivity, or a reduced effective thermal conductivity in the vertical direction. Having such a modified thermal conductivity, the substrate 100 is highly useful in order to improve lateral crystal growth in the lateral solidification process, as will be now described.

Referring next to Fig. 2, the lateral solidification of silicon in accordance with the above-noted sequential lateral solidification technique is illustrated. Fig. 2 represents a cross sectional view of the silicon film 150 as it may appear during lateral solidification, with liquid silicon 210 solidifying into crystalline silicon 220 at a velocity Vg. As the liquid silicon solidifies through the motion of the interface 230, latent heat is released at the interface 230 due to reduction in enthalpy associated with the liquid to solid transition. The lateral solidification will continue along moving boundary 230 until either impingement of the interface with another similar interface, or until nucleation.

Referring next to Fig. 3a, a graphs showing the relationship between the temperature of solidifying silicon and the position of such silicon around a liquid to solid interface is shown, where T_{bulk} represents the temperature of the bulk liquid silicon as it cools, T_{int} represents the temperature of the silicon as the interface 230, and T_{mp} represents the melting temperature of silicon. As those skilled in the art will appreciate, the temperature of T_{int} will impact the growth rate of the forming crystal, with a lower temperature leading to a faster growth rate. Likewise, when T_{bulk} reaches a certain temperature range, random nucleation will commence, ceasing the crystal growth process.

Referring to Fig. 3b, two possible temperature profiles for solidifying silicon are shown, at a time t after laser irradiation. The temperature profile 310 represents a poor temperature profile, as the high interface temperature will cause slow lateral solidification, and the low temperature in the region away from the interface 230 will cause the temperature of those regions of liquid silicon to drop below the nucleation temperature range, ΔT_N. In contrast the temperature profile 320 represents a optimal temperature profile, with a lower interface temperature causing more rapid lateral solidification, and a less cooling in the liquid silicon away from the interface 230 such

that the temperature remains above the nucleation temperature range for a loner time.

Referring next to Fig. 4, a substrate in accordance with a second preferred embodiment of the present invention is now described. As shown in Fig. 4, the substrate 400 includes a bulk glass plate layer 410, a low conductivity layer 420, a subsurface melting layer 430, a silicon dioxide layer 430 and a semiconductor layer 450 made from a predetermined semiconductor material. The low conductivity layer 420, a silicon dioxide layer 430 and semiconductor layer 450 may be fabricated as described above in connection with substrate 100 by any combination of thin film formation techniques, such as physical or chemical vapor deposition, electrochemical deposition, or spin coating.

The subsurface melting layer 430 must have a melting point which is less than or equal to that of the predetermined semiconductor material, and preferably should exhibit an increased conductivity after melting. In addition, it is highly preferable to use a material having a high latent heat for the melting layer 430, such as a Silicon Germanium alloy. A 1000 Angstrom thick layer of Silicon Germanium alloy would be suitable for melting layer 430. Alternatively, an approximately 1000 Angstrom thick layer of certain metals such as Aluminum or Copper could be used for melting layer 430.

When fabricated as described above, the substrate 400 will exhibit either a reduced overall effective thermal conductivity, or a reduced effective thermal conductivity in the vertical direction. When used in the sequential lateral solidification process, the melting layer 430 will partially or completely melt, thereby storing heat. Later, as the melting layer solidifies, heat will be released through the phase transformation from liquid to solid, thereby preventing rapid cooling of the overlying silicon layer 450, and delaying nucleation. Thus, as shown in Fig. 3b, the solidification of the melting layer 430 will have the effect of moving the temperature profile of the solidifying silicon layer up from profile 310 to profile 320 in the regions away from the boundary 230. With such a modified thermal conductivity, the substrate 400 is likewise highly useful in order to improve lateral crystal growth in the lateral solidification process.

The foregoing merely illustrates the principles of the invention. Various modifications and alterations to the described embodiments will be apparent to those

skilled in the art in view of the teachings herein. For example, the silicon layer 150, 450 may be replaced by other semiconductors such Germanium, Silicon Germanium, Gallium Arsenide, or Gallium Nitride, with, in the case of the second embodiment, suitable modifications to the melting layer 430. Likewise, other metals may be used for the high conductivity layer 130. Moreover, the high and low conductivity layers may be either a single unitary layer, or consist of multiple sub-layers. It will thus be appreciated that those skilled in the art will be able to devise numerous systems and methods which, although not explicitly shown or described herein, embody the principles of the invention and are thus within the spirit and scope of the invention.

CLAIMS

1. A substrate having modified effective thermal conductivity for use in the sequential lateral solidification process, comprising:

(a) a base layer having a base layer conductivity and at least a top surface;

(b) a low conductivity layer having a conductivity which is less than said base layer conductivity, a first side and a second side, said low conductivity layer first side formed adjacent to said top surface of said base layer;

(c) a high conductivity layer having a conductivity which is greater than said base layer conductivity, a first side and a second side, said high conductivity layer first side formed adjacent to said second side of said low conductivity layer; and

(d) a semiconductor layer formed on said second side of said high conductivity layer.

2. The substrate of claim 1, wherein said low conductivity layer comprises porous glass.

3. The substrate of claim 2, wherein said low conductivity layer is in the range of 5,000 Angstroms to 2 microns thick.

4. The substrate of claim 1, wherein said high conductivity layer comprises a metal.

5. The substrate of claim 4, wherein said high conductivity layer is sufficiently thin so as to not increase the overall vertical conductivity of said substrate.

6. The substrate of claim 4, wherein said high conductivity layer is in the range of 50 to 5,000 Angstroms thick.

7. The substrate of claim 1, further comprising a silicon compound layer having said predetermined silicon compound conductivity, a first side and a second side, wherein said silicon compound layer first side is formed adjacent to said second side of said high conductivity layer and said semiconductor layer is formed on said second side of said silicon compound layer.

8. The substrate of claim 7, wherein said silicon compound comprises silicon dioxide, and said silicon compound layer is sufficiently thick to prevent diffusion of impurities from said high conductivity layer.

9. The substrate of claim 8, wherein said silicon compound layer is in the range of 200 to 2,000 Angstroms thick.

10. The substrate of claim 1, wherein said base layer comprises glass.

11. A substrate having modified effective thermal conductivity for use in the sequential lateral solidification process, comprising:

(a) a base layer having a base layer conductivity and at least a top surface;

(b) a low conductivity layer having a conductivity which is less than said base layer conductivity, a first side and a second side, said low conductivity layer first side formed adjacent to said top surface of said base layer;

(c) a subsurface melting layer having a melting point which is less than or equal to that of a predetermined semiconductor material, a first side and a second side, said subsurface melting layer first side formed adjacent to said second side of said low conductivity layer;

(d) a silicon compound layer having a first side and a second side, said silicon compound layer first side formed adjacent to said second side of said subsurface melting layer; and

(e) a semiconductor layer comprising said predetermined semiconductor material and formed on said second side of said silicon compound layer.

12. The substrate of claim 11, wherein said low conductivity layer comprises porous glass.

13. The substrate of claim 12, wherein said low conductivity layer is in the range of 5,000 Angstroms to 2 microns thick.

14. The substrate of claim 11, wherein said melting layer exhibits an increased conductivity after melting.

15. The substrate of claim 11, wherein said melting layer comprises a material having a high latent heat.

16. The substrate of claim 15, wherein said melting layer comprises Silicon Germanium.

17. The substrate of claim 16, wherein said melting layer is approximately 1000 Angstroms thick.

18. The substrate of claim 11, wherein said silicon compound comprises silicon dioxide, and said silicon compound layer is sufficiently thick to prevent diffusion of impurities from said melting layer.

19. The substrate of claim 18, wherein said silicon compound layer is in the range of 200 to 2,000 Angstroms thick.

20. The substrate of claim 11, wherein said base layer comprises glass.

Fig 1

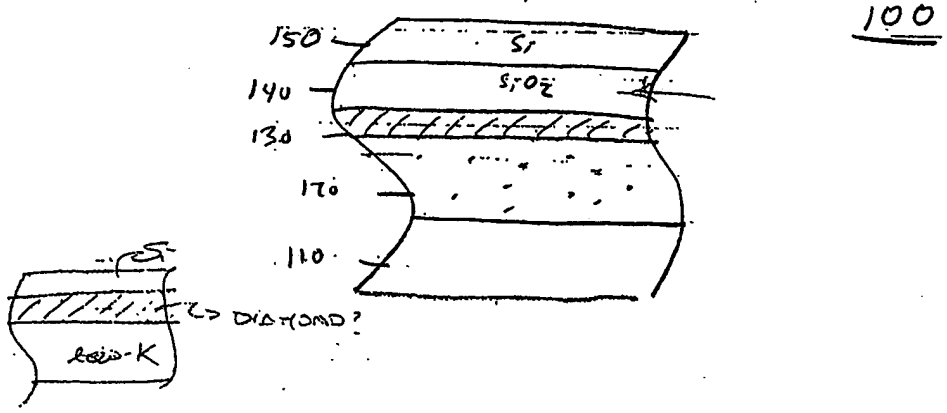


Fig 2

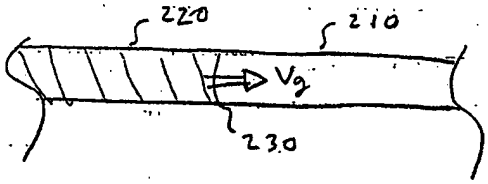


Fig. 3a

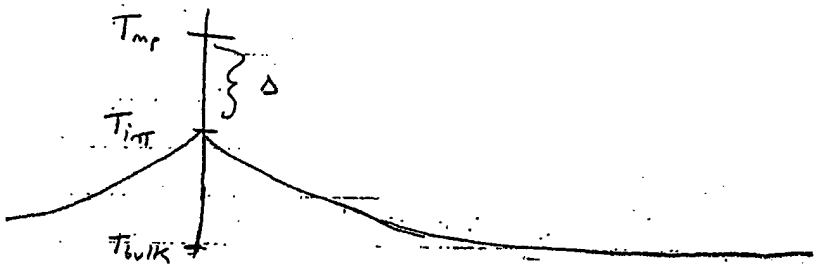


Fig. 3b

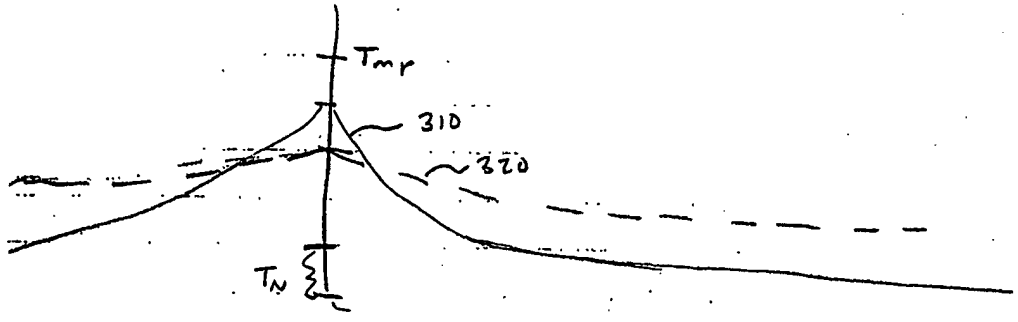
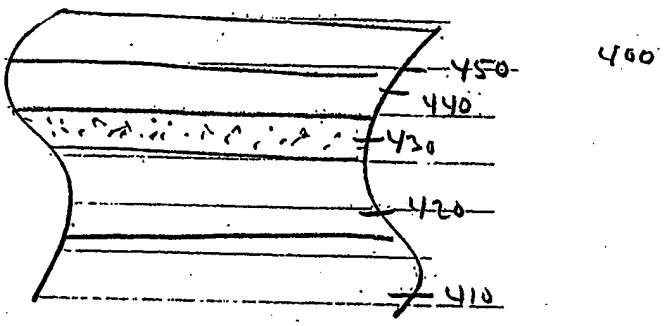


Fig 4



INTERNATIONAL SEARCH REPORT

Inte tional Application No
PCT/US 01/44563

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01L21/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01L C30B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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[X] Further documents are listed in the continuation of box C.

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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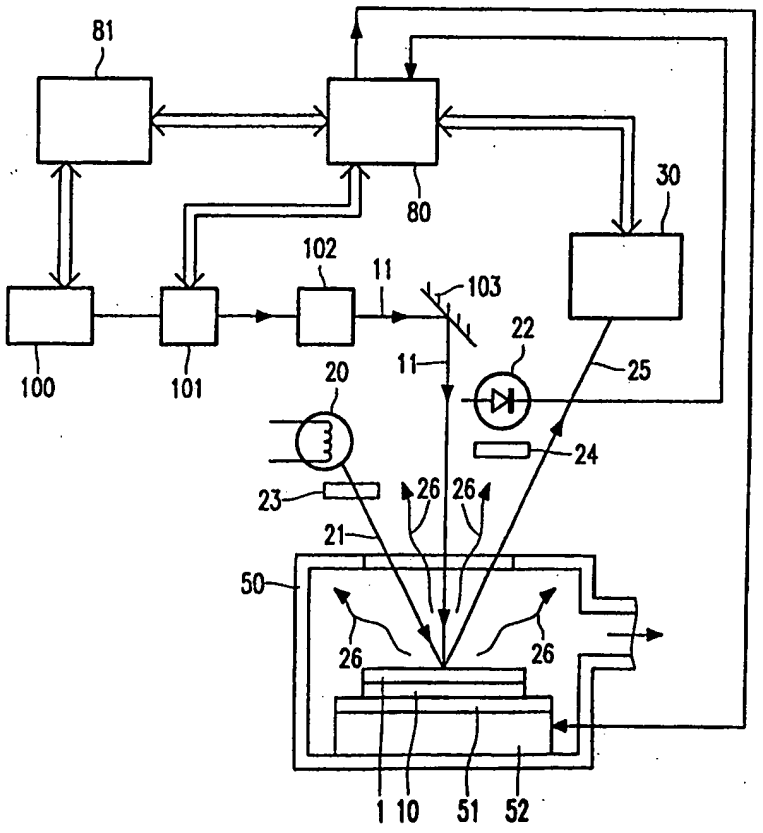
(54) Title: ELECTRONIC DEVICE MANUFACTURE BY ENERGY BEAM CRYSTALLISATION

(57) Abstract

The invention provides a method of manufacturing a large-area electronic device, for example a flat panel display, comprising thin-film circuit elements, and also laser apparatus for crystallising a portion of a semiconductor thin-film (1) with a beam (11) of set energy. The energy of the beam (11) is set in accordance with the output from a light detector (22) to regulate the crystallisation of a device portion (3, 4 and/or 5) of a semiconductor thin film (1) at which the beam (11) is subsequently directed with its set energy. The light detector (22) monitors the surface quality of a previously crystallised portion (2). In accordance with the present invention, the light detector (22) is located at a position outside the specular reflection path (25) of the light returned by the surface area of the crystallised portion (2) and detects a threshold increase (D) in intensity (I_s) of the light (26) being scattered by the surface area of the crystallised portion. This treshold increase (D) occurs when the energy (E_p) of the beam (11) is increased sufficiently to cause the onset of surface roughening.



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DESCRIPTION

ELECTRONIC DEVICE MANUFACTURE BY ENERGY BEAM CRYSTALLISATION

This invention relates to methods of manufacturing electronic devices comprising a thin-film circuit element, including the step of directing an energy beam at a surface of a semiconductor thin film to crystallise at least a portion of the thin film. The device may be a flat panel display (for example, a liquid crystal display), or a large area image sensor or several other types of large-area electronic device (for example, a thin-film data store or memory device). The invention also relates to apparatus for crystallising a portion of a semiconductor thin film.

There is much interest in developing thin-film circuits with thin-film transistors (hereinafter termed TFTs) and/or other semiconductor circuit elements on insulating substrates for large-area electronics applications. These circuit elements fabricated with portions of an amorphous or polycrystalline semiconductor film may form the switching elements in a cell matrix, for example in a flat panel display as described in United States Patent Specification US-A-5,130,829 (our reference PHB 33646), the whole contents of which are hereby incorporated herein as reference material.

Recent developments involve the fabrication and integration of thin-film circuits (usually with polycrystalline silicon) as, for example, integrated drive circuits for such a cell matrix. In order to increase the circuit speed, it is advantageous to use semiconductor material of good crystal quality and high mobility for thin-film islands of the TFTs of these circuits. It is known to deposit a semiconductor thin film of amorphous material or of low crystallinity material and then to form the material of high crystallinity in at least a device portion of this film by exposure to an energy beam from a laser.

United States Patent Specification US-A-5,372,836 discloses a method of manufacturing an electronic device comprising a thin-film circuit element,

which method includes the steps of:

(a) directing an energy beam at a surface area of a semiconductor thin film on a substrate to crystallise at least a portion of the thin film,

(b) monitoring the surface quality of the crystallised portion of the thin film by directing light at the surface area of the crystallised portion and by detecting with a light detector the light returned from the surface area, the light detector giving an output indicative of the monitored surface quality, and

(c) setting the energy of the beam in accordance with the output from the light detector to regulate the crystallisation of a device portion of a semiconductor thin film at which the beam is subsequently directed with its set energy.

The whole contents of US-A-5,372,836 are hereby incorporated herein as reference material.

In the method and apparatus described in US-A-5,372,836 the light detector is a spectroscope 16. The light source 17 for directing the light at the surface area of the crystallised thin-film portion has a wide wavelength band from 200nm to 500nm. The spectroscope 16 is located in the specular reflection path of the light returned by the surface area of the film. Sample outputs of the spectroscope 16 are depicted as graphs in Figures 18 to 21 of US-A-5,372,836, showing the bandgap spectral reflectance of a film in various crystallisation states. The spectral reflectance shown in these graphs are for a polycrystalline silicon film in an ideal state in Figure 18, for an amorphous silicon film in Figure 19, for an amorphous silicon film insufficiently transformed into polycrystalline silicon in Figure 20 due to an insufficient energy of the laser beam, and for a film damaged by an excessive energy of the laser beam in Figure 21.

In the method described in US-A-5,372,836, the semiconductor thin film is deposited on the substrate as hydrogenated amorphous silicon material by a plasma CVD (chemical vapour deposition) process. The device portion of the film is subjected to multiple exposures with the laser beam, the energy of the laser beam being progressively increased with each exposure. Initially, the

energy levels of the laser beam are set such that hydrogen is gradually discharged from the film without crystallising or damaging the film. The energy of the beam is finally set such that the film is transformed into a polycrystalline silicon material. The spectroscope 16 provides a good source of information on the quality of the exposed film portion at the different stages.

As can be seen from Figures 18 to 20 of US-A-5,372,836, such an arrangement with specular reflection to a spectroscope can provide a good indication of whether the film is still inadequately crystallised so enabling increased crystallisation of the film to be carried out by a further exposure with an increased beam energy. As shown in Figure 21, such an arrangement is also good for detecting when an excessive energy level has been used and has damaged the film. However, as described in column 13, lines 12 to 15, when the spectroscopic reflectance distribution shown in Figure 21 is detected, the sample is a defective one. It is then too late to remedy the situation, and the sample can only be discarded as being defective.

It is an aim of the present invention to provide a different light detection arrangement which provides an indication of a threshold change in monitored surface quality of the thin film prior to the occurrence of such damage, and so permits the use of a high beam energy in order to provide crystallised semiconductor material of good crystal quality and high mobility.

According to a first aspect of the present invention there is provided a method of manufacturing an electronic device comprising a thin-film circuit element, which method includes the steps of:

(a) directing an energy beam at a surface area of a semiconductor thin film on a substrate to crystallise at least a portion of the thin film,

(b) monitoring the surface quality of the crystallised portion of the thin film by directing light at the surface area of the crystallised portion and by detecting with a light detector the light returned by the surface area, the light detector giving an output indicative of the monitored surface quality, and

(c) setting the energy of the beam in accordance with the output from

the light detector to regulate the crystallisation of a device portion of a semiconductor thin film at which the beam is subsequently directed with its set energy,

characterised in that the light detector is located at a position outside the specular reflection path of the light returned by the surface area of the crystallised portion and detects a threshold increase in intensity of the light being scattered by the surface area of the crystallised portion, which threshold increase occurs when the energy of the beam is increased sufficiently to cause an onset of surface roughening, and in that, when crystallising the device portion for the thin-film circuit element during the step (c), the energy of the beam is set to a value as determined by the detection of said threshold increase.

The present invention utilises a discovery by the present inventors that, as the beam energy is increased, there is an onset of surface roughening which occurs before the thin film is damaged by an excessive energy level. The onset of surface roughening seems to relate to a sudden appearance of a spatially periodic perturbation (ripples) in the crystallised semiconductor material as described in the article "Surface roughness effects in laser crystallised polycrystalline silicon" by the present inventors, published in Applied Physics Letters, Vol 66, No 16, 17 April 1995, pages 2060 to 2062, the whole contents of which are incorporated herein as reference material. this onset of surface roughening precedes an increase in grain size which occurs as melt-through of the film is approached, i.e when the absorbed energy of the beam in the film is sufficient to form a molten zone which reaches through most of the thickness of the film to the substrate. The present inventors find that this particular onset of surface roughening cannot be detected with adequate sensitivity using specularly reflected light. However, an arrangement in accordance with the present invention which detects light scattered by the crystallised surface area is able to detect the particular onset of surface roughening and has sufficient sensitivity for reliable and accurate detection in a manufacturing situation. Thus, the present invention permits detection of this

onset of surface roughening to be used to set the beam energy for a large-grain high-mobility crystal state of the thin film.

Thus, the present invention permits the energy of the beam to be increased to a value (as reliably determined by the detection of this threshold increase in scattered light) for producing large-grain good-quality high-mobility crystal material, below an excessive energy level associated with damage to the film. Good quality crystallised film portions with electron mobilities in excess of $100cm^2.V^{-1}.s^{-1}$ can be reliably obtained in accordance with the present invention. Generally speaking, the optimum beam energy for maximum film mobility does not coincide with the energy at which the onset of this surface roughening occurs as detected by said threshold increase in scattered light, but occurs at a slightly higher energy. Thus, for maximum film mobility, the energy of the beam is set to a value of (E + dE), where E is the energy at which this particular onset of surface roughening is detected and dE is a small incremental increase (for example 10 to 60 $mJ.cm^{-2}$) for typical thicknesses of the thin film required for most circuit elements of large area electronic devices. The value of dE increases with increasing values of E, as described hereinafter.

In a batch manufacturing process where a batch of thin films on substrates are crystallised with the energy beam, the energy of the beam may be set to an operational value when processing a first substrate in the batch, and this operational value may then be used for subsequent substrates in the batch. However, it is advantageous to monitor the surface quality and so to regulate the energy value of the beam for each substrate in the batch. Thus, the present inventors find that the threshold increase in scattered light intensity occurs at an energy value E which is dependent on the thickness of the thin film.

The present invention permits the energy value of the beam to be set in accordance with the actual thickness of the film of any given sample, so that the energy value can be set for each sample. Thus, the portion crystallised in step (a) for monitoring in step (b) may be a part of the same semiconductor thin film as the device portion subsequently crystallised with the beam of set

energy in step (c). The device portion of the thin film may be a separate area from a test surface area of the film where the monitoring of step (b) is carried out. Thus, a method in accordance with the present invention may be further characterised by the steps of directing the energy beam at a test surface area of the semiconductor film in step (a), setting the energy of the beam to the set value by monitoring the quality of the crystallised test surface area by means of the scattered light in step (b), and directing the energy beam with the set value of energy at a different surface area of the same semiconductor thin film to crystallise the device portion for the thin-film circuit element. It is convenient to provide the test area as a peripheral area of the semiconductor thin film. Thus, the energy beam may first be scanned along the test area to regulate its energy, after which it may be scanned along the device area with the set value.

According to a second aspect of the present invention there is provided apparatus for crystallising a portion of a semiconductor thin film on a substrate comprising

a laser for generating an energy beam to crystallise the portion of the thin film,

a processing cell containing a support for mounting the substrate,

an optical system between the laser and the processing cell to direct the beam from the laser at a surface area of the thin film when the substrate is mounted in the processing cell,

adaptor means for changing the energy of the beam incident on the film,

a light source for directing light at the surface area of the crystallised portion of the thin film, and

a light detector for detecting the light returned by the surface area, the light detector giving an output indicative of the surface quality,

characterised in that the light detector is located at a position outside the specular reflection path of the light returned by the surface area of the crystallised portion and has sufficient sensitivity to detect a threshold increase in intensity of the light being scattered by the surface area of the crystallised portion, which threshold increase occurs when the energy of the beam is

increased sufficiently to cause the onset of surface roughening, and control means take an input from the output of the light detector and provide an output to the adaptor means for setting the energy of the beam to a value as determined by the detection of said threshold increase.

Preferably the energy of the beam is adjusted to the set value by means of an attenuator or other optical element which is located in the path of the beam, and which forms part of the optical system between the laser and the processing cell. Using an optical element as the adaptor means is more preferable than adjusting the electrical power supply to the laser, because adjustment of the laser itself via the power supply during operation tends to cause instability.

The scattered light which is detected may be directed at the surface area of the crystallised portion from a light source independent of the beam used for crystallising the thin-film portion. However, the beam used for crystallising the thin-film portion may be generated by a laser, and this laser and its generated beam may also provide the light which is scattered to the light detector for monitoring the surface quality in step (b) of the method.

These and other features in accordance with the present invention, and their advantages, are illustrated specifically in embodiments of the invention now to be described, by way of example, with reference to the accompanying diagrammatic drawings, in which:

Figure 1 is a schematic of laser apparatus in accordance with the present invention and suitable for use in a manufacturing method also in accordance with the present invention;

Figure 2 is a schematic cross-sectional view of a semiconductor thin film on a substrate during the manufacture of an electronic device in accordance with the present invention;

Figure 3 is a plan view of different areas of the semiconductor film of the Figure 2;

Figure 4 is a cross-section view of one example of a TFT fabricated with

a film portion crystallised in a method in accordance with the invention;

Figure 5 is a graph of electron mobility (μ_n) in $cm^2.V^{-1}.s^{-1}$ in a crystallised film portion, as a function of peak laser energy (E_p) in $mJ.cm^{-2}$ per pulse for different film thicknesses (t_{Si}) in nm; and

Figure 6 is a graph of scattered light intensity I_s in arbitrary units as a function of peak laser energy (E_p) in $mJ.cm^{-2}$ per pulse for a film thickness t_{Si} of 40nm.

It should be noted that Figures 1 to 4 are diagrammatic and not drawn to scale. Relative dimensions and proportions of parts of these Figures have been shown exaggerated or reduced in size, for the sake of clarity and convenience in the drawings. The same reference signs are generally used to refer to corresponding or similar features in different embodiments.

As illustrated by examples in Figures 1 to 3, the present invention provides both a method of manufacturing a large-area electronic device (for example a flat panel display similar to that disclosed in US-A-5,130,829) and also apparatus for crystallising a portion of a semiconductor thin film 1 in such a method.

The method includes the steps of:

(a) directing an energy beam 11 at a surface area of a semiconductor thin film 1 on a substrate 10 to crystallise at least a portion 2 of the thin film 1 (Figure 2),

(b) monitoring the surface quality of the crystallised portion 2 of the thin film 1 by directing light 21 at the surface area of the crystallised portion 2 and by detecting with a light detector 22 the light returned by the surface area, the light detector 22 giving an output indicative of the monitored surface quality (Figures 1 and 2), and

(c) setting the energy of the beam 11 in accordance with the output from the light detector 22 to regulate the crystallisation of a device portion 3,4 and/or 5 of a semiconductor thin film 1 at which the beam 11 is subsequently directed with its set energy (Figures 1 and 3).

In accordance with the present invention, the light detector 22 is located at a position outside the specular reflection path 25 of the light returned by the surface area of the crystallised portion and detects a threshold increase (D in Figure 6) in intensity I_s of the light 26 being scattered by the surface area of the crystallised portion, which threshold increase D occurs when the energy E_p of the beam 11 is increased sufficiently to cause the onset of surface roughening, and in that, when crystallising the device portion 3,4 and/or 5 for a thin-film circuit element (for example a polycrystalline silicon TFT) during the step (c), the energy of the beam 11 is set to a value as determined by the detection of said threshold increase D.

The apparatus, as illustrated in Figure 1 comprises a laser 100 for generating the energy beam 11 to crystallise the portion of the thin film 1; a processing cell 50 containing a support 51 for mounting the substrate 10; an optical system 101 to 103 between the laser 100 and the processing cell 50 to direct the beam 11 from the laser 100 at a surface area of the thin film 1 when the substrate 10 is mounted in the processing cell 50; and adaptor means 81,101 for changing the energy of the beam 11 incident on the film 1; a light source 20 for directing light 21 at the surface area of the crystallised portion 2 of the thin film 1, and a light detector 20 for detecting the light returned by the surface area, the light detector 20 giving an output indicative of the surface quality.

In accordance with the present invention, the light detector 22 is located at a position outside the specular reflection path 25 of the light returned by the surface area of the crystallised portion 2 and has sufficient sensitivity to detect a threshold increase D in intensity I_s of the light 26 being scattered by the surface area of the crystallised portion, which threshold increase D occurs when the energy of the beam 11 is increased sufficiently to cause the onset of surface roughening, and control means 80 couple the light detector 22 to the adaptor means 81,101 to take an input from the output of the light detector 22 and to provide an output control signal to the adaptor means 81,101 for setting the energy of the beam 11 to a value as determined by the detection of said

threshold increase D.

Preferably a pulsed laser beam 11 of an ultraviolet wavelength is used, generated by an excimer laser 100. A laser beam 11 of ultraviolet wavelength has the known advantage of permitting control of its absorption depth in the semiconductor material of the film 1. Useful laser wavelengths are 248nm from a KrF laser, or a wavelength of 308nm from an XeCl laser, or a wavelength of 351nm from an XeF laser.

Apart from the inclusion and use of the scattered light detector 22, the laser apparatus of Figure 1 may be similar to that described in US-A-5,372,836 and/or in the Journal article "Beam Shape Effects with Excimer Laser Crystallisation of Plasma Enhanced and Low Pressure Chemical Vapour Deposited Amorphous Silicon" by S D Brotherton, D J McCulloch et al in Solid State Phenomena, Vols 37 to 38 (1984), pages 299 to 304. The whole of this Solid State Phenomena article are hereby incorporated herein as reference material.

Thus, the laser apparatus of Figure 1 comprises an electrical power supply 81 for the laser 100. The power supply 81 is regulated by a computer control system 80. The computer control system 80 also regulates the movement of an X-Y table 52 for scanning the laser beam 11 along the surface of the thin film 1. In the arrangement illustrated by way of example in Figure 1, the X-Y table 52 moves the substrate 10, although an arrangement as illustrated in US-A-5,372,836 may be used in which an X-Y table moves an optical element to move the laser beam 11. In the example illustrated in Figure 1, the substrate support 51 is a susceptor which is mounted on the X-Y table 52. The position of the X-Y table 52 is controlled by an input signal from the computer control system 80. The processing cell 50 may be, for example, a vacuum chamber.

The optical system 101 to 103 between the laser 100 and the processing cell 50 may comprise an attenuator 101, an homogeniser 102 for controlling the beam shape, and one or more total-reflection mirrors 103 for deflecting the beam 11. Typically the optical system 101 to 103 also comprises other optical

elements, for example one or more apertures and lenses. The attenuator 101 controls the energy of the beam 11 transmitted from the laser 100 to the processing cell 50. This attenuator 101 may be of known form, for example one or more tilting transmission plates, the angle of which is varied to vary the transmitted energy level. The angle of the plates is set in known manner by an output signal from the computer control system 80.

The apparatus may comprise a spectroscope 30 for generating band-gap spectroscopic reflectance distributions as illustrated in Figures 18 to 21 of US-A-5,372,836. However, most importantly, the apparatus comprises the scattered light detector 22 which is provided and used in accordance with the present invention. Thus, the light detector 22 provides its output to the computer control system 80. The computer control system 80 then sets the energy of the beam 11 to a value (E + dE) as determined by the detection of a threshold increase in the scattered light 26. This change in the energy of the beam 11 may be effected via an output signal from the computer control system 80 to the electrical power supply 81 of the laser 100. However, it is preferable not to disturb the electrical supply to the laser 100 during its operation. Therefore, it is preferable to change the energy of the beam 11 by the computer control system 80 providing an output to the attenuator 101.

The light 21 which is directed at the surface of the crystallised thin-film portion 2 may be from a light source 20 independent of the beam 11 used for crystallising the thin-film portion 2. The wavelength of the scattered light 26 may therefore be made quite different from that of the laser beam 11, so that the light detector 22 can readily respond to the scattered light 26 from source 20, in distinction from any returning light from the laser beam 11. The light 21,26 may be of an ultraviolet wavelength, for example at about 325nm when the laser beam 11 is at 248nm. A filter and shutter arrangement 23 and 24 may be present in front of each of the light source 20 and light detector 22 to determine the wavelength and timing of the light transmission from the source 20 to the detector 22. The scattered light detector 22 may be of any convenient type, for example a photodiode.

However, instead of using a separate light source 20 with the detector 22, the laser beam 11 used for crystallising the thin-film portion 2 may provide the light 26 which is scattered to the light detector 22 for monitoring the surface quality. Beam 11 may have a spatial energy distribution (for example a Gaussian distribution in the scan direction) comprising a peak energy rising from a leading edge of increasing energy and falling off in a trailing edge of reducing energy. The energy regulation achieved in accordance with the present invention may be such that the peak energy value is just sufficient to achieve melt-through of the film thickness; in this case, the trailing edge of reducing energy allows the crystallisation of smaller grains as nuclei for large grain growth in the film 1, which may be even more optimum for providing high electron field-effect mobilities. Furthermore, the leading and trailing edges permit the laser beam 11 to be used in monitoring the crystallisation quality of the cooling film 1 after melt-through. Thus, with a pulsed laser beam 11, the leading edge of the next pulse provides the incident light which is scattered as light 26 to the detector 22 from the surface of the cooling film portion 2 which has crystallised after melt-through by the previous pulse. In this case, for example, the beam 11 and hence also the scattered light 26 may have a wavelength of 308nm. The increasing energy in the leading edge of such a pulse is also advantageous in achieving a gradual release of hydrogen in the laser crystallisation of a hydrogen-rich PECVD a-Si:H film 1 as described in the said Solid State Phenomena article. However, a shaped beam having such a spatial energy distribution may also be used to crystallise silicon films having substantially no damaging hydrogen content.

The present invention may be used to optimise crystal grain size and field-effect mobility in polycrystalline silicon films for thin-film circuit element fabrication in known types of large-area electronic device. By way of example, the experimental results illustrated in Figures 5 and 6 were obtained by fabricating so-called "top-gate co-planar polysilicon TFTs" similar to the TFT shown in Figure 6 of US-A-5,130,829. Such a top-gate co-planar polysilicon TFT is illustrated in Figure 4. The gate electrode 42 is present on a gate

dielectric film 41 on a crystallised portion of the thin-film 1 which provides the channel region of the TFT. Doped source and drain regions 43 and 44 are formed in the film 1 and contacted by metal film electrodes 45 and 46. Such TFTs may form the switching elements of an array of a display matrix as described in US-A-5,130,829. However, they may also form circuit elements in row and column driver circuits integrated on the same substrate 10 as the display array.

By way of example, Figure 3 shows in plan view a thin film 1 on a substrate 10 which is subsequently divided into four display components by scribing along the lines M-M, M'-M', and N-N. Each display component comprises an array area 5 bordered on two sides by a row driver circuit area 4 and a column driver circuit area 3. The whole of the thin film 1 (i.e areas 3, 4 and 5) may be crystallised with the laser beam 11. However, if desired, the array area 5 may be retained as amorphous silicon material and only the column and row driver circuit areas 3 and 4 may be crystallised with the beam 11. The arrangement illustrated in Figure 3 also comprises a test surface area 2 which is a peripheral area of the semiconductor thin film 1 on the substrate 10. This test area 2 is part of the same semiconductor thin film 1 as the device portions 3, 4 and 5. In this case, the method of manufacture includes the steps of directing the beam 11 at the test area 2 in step (a), regulating the energy of the beam 11 to the set value by monitoring the quality of the crystallised test surface area 2 by means of the scattered light 26 in step (b), and then directing the beam 11 with the set value of energy at the different surface areas 3, 4 and/or 5 to crystallise these different portions for the thin-film circuit elements of the display components.

The present invention may be used to crystallise semiconductor thin films 1 having a hydrogen content. However, as described in the Applied Physics Letters article and the Solid State Phenomena article, the release of hydrogen from the film when scanned with a laser beam can result in significant surface roughening. In order to illustrate the different surface roughening mechanism which is utilised in accordance with the present invention, it is

preferable to avoid any confusion with surface roughening caused by hydrogen release. For this reason, the experimental results given in Figures 5 and 6 are for a semiconductor thin film of a silicon material which has substantially no hydrogen content at least when crystallising the device portion 3,4,5 of the thin film 1 for the thin-film circuit elements. The film 1 may be deposited by PECVD (plasma enhanced chemical vapour deposition) with a hydrogen content which may be slowly released by gradual heating before carrying out any laser crystallisation treatment. However, the thin film 1 may be deposited by LPCVD (low pressure chemical vapour deposition) with only a very low hydrogen content. In the case of Figures 5 and 6, the pre-cursor films 1 crystallised by the beam 11 were deposited as amorphous silicon LPCVD layers at 540°C. The substrate 10 comprised a glass plate 10b capped with an insulating layer 10a of silicon dioxide. The silicon film 1 was deposited on this insulating layer 10a. For the results of Figures 5 and 6, a gate dielectric 41 of silicon dioxide was deposited to a thickness of 140nm in a PECVD reactor at 300°C. A TFT having an aluminium gate 42 and the co-planar configuration illustrated in Figure 4 was formed with the crystallised film 1. The silicon film 1 is patterned by etching into individual islands for the individual TFTs and any other thin-film circuit elements of the device.

The peak energy E_p given in Figures 5 and 6 is the peak energy occurring within a semi-Gaussian distribution for the beam 11, for example as described in the Solid State Phenomena article. E_p is the peak energy density in $mJ.cm^{-2}$ for each pulse of the beam 11. Typically the pulse duration is about 30ns (nanoseconds). The device portions of the film 1 were subjected to approximately 140 pulses to obtain the mobility results shown in Figure 5.

Figure 5 shows the variation of electron field effect mobility (μ_n) with both the incident peak energy (E_p) in each laser pulse and with the thickness (t_{Si}) of the LPCVD pre-cursor film 1. There is a clear pattern to these mobility results. In region A there is an initial increase in mobility (and its saturation in region B at 40 to $60cm^2.V^{-1}.S^{-1}$) which arises from the primary conversion of the surface of the amorphous silicon film 1 to polycrystalline silicon. Under these

conditions, the crystallised film 1 appears to be stratified with an upper layer of grains about 100nm wide on a finer grain background. In region C there is a second increase in mobility which arises as the melt-through condition is approached. The energies required for melt-through are strongly dependent on the film thickness t_{Si}. Over the range of thicknesses shown, the melt-through threshold voltage varied approximately linearly with film thickness t_{Si}. TEM (transmission electron microscope) investigation of these films in the region C has shown both an increase of 2 to 3 times in grain size and an absence of stratification in samples having the peak mobility. The peak mobility was about $175cm^2.V^{-1}.s^{-1}$ for the 40nm thick film 1, and in excess of $200cm^2.V^{-1}.s^{-1}$ for the 80nm thick film 1. The mobility is observed to fall off after these peak values, apparently due to the onset of crystallographic damage in the film as a result of an excessive energy of the beam 11.

The transition from saturation region B to the second increasing region C is well defined for the films 1 with thicknesses t_{Si} of 80nm and 145nm. This transition from regions B to C is not so clear in Figure 5 for the film 1 having a thickness of 40nm. However, the occurrence of a related transition can be seen quite clearly by examining the scattered light 26 from the 40nm thick film 1, as illustrated in Figure 6. Thus, Figure 6 shows that there is an order of magnitude increase D in the scattered light 26 as a characteristic surface roughening of the film occurs before melt-through. This threshold increase D in scattered light 26 is easily detected with the light detector 22. The results shown in Figure 6 were for light 21,26 of 325nm wavelength. A pulsed laser beam of 248nm was used for the crystallisation of the film 1.

This onset of surface roughening seems to be related to the appearance of a periodic spatially varying roughness as described and shown in the said Applied Physics Letters article. It should be noted that there is a reduction of only a few percent in the reflected light 25 from the film surface as this roughening occurs. This small change in surface reflectance provides inadequate sensitivity for reliably monitoring the occurrence of this onset. By contrast therewith, there is an order of magnitude increase in the scattered light

26 as this onset occurs.

It should also be noted that the energy E at which the onset of surface roughening occurs (as detected by this threshold increase D in scattered light 26) is at a lower value than the optimum beam energy for maximum film mobility as shown in Figure 5. Generally speaking, for a semiconductor thin film of silicon having a thickness in the range of 20nm to 60nm, this optimum beam energy is within 60mJ.cm^{-2} of the value E causing the onset of surface roughening as detected by the threshold increase D in intensity of the scattered light 26. Thus, for example, for the 40nm thick film 1 the threshold increase D in scattered light intensity as shown in Figure 6 occurs between 225 and 240mJ.cm^{-2}. The optimum beam energy for maximum field-effect electron mobility as illustrated in Figure 5 occurs at about 270mJ.cm^{-2}. Therefore, the energy of the beam 11 used for crystallisation of device portions 3,4, and/or 5 of the film 1 in step (c) is preferably set to a regulated value which is about 25mJ.cm^{-2} higher than the energy threshold indicated in Figure 6. Thus, for maximum film mobility, the energy of the beam 11 is set to a value of (E +dE), where E is the energy at which the particular onset of surface roughening is detected by the scattered light detector 22 as illustrated in Figure 6, and where dE is an incremental increase which is found by the present inventors to be dependent on the thickness t_{Si} of the thin film 1 and which is thus also related to the energy value E. For film thicknesses t_{Si} of less than 40nm the set value (E + dE) converges rapidly towards E, whereas for thicker films 1 the incremental increase dE increases strongly as the thickness t_{Si} increases. Thus, the incremental increase dE is nearly 150mJ.cm^{-2} for a film thickness of t_{Si} of 80nm. The films 1 required for most TFTs and other thin-film circuit elements of large-area electronic devices today have film thicknesses of less than 50nm, and the general trend is towards even thinner films, for example 40nm, 30nm and less. The value of the incremental increase dE (to be added to the scattered-light monitored value E so as to set the beam energy for optimum crystal growth) can be stored in a look-up table of the computer control system 80.

From reading the present disclosure, many modifications and variations will be apparent to persons skilled in the art. Such modifications and variations may involve equivalent features and other features which are already known in the art and which may be used instead of or in addition to features already disclosed herein. Although claims have been formulated in this Application to particular combinations of features, it should be understood that the scope of the disclosure of the present application includes any and every novel feature or any novel combination of features disclosed herein either explicitly or implicitly and any generalisation thereof, whether or not it relates to the same invention as presently claimed in any Claim and whether or not it mitigates any or all of the same technical problems as does the present invention. The Applicants hereby give notice that new claims may be formulated to such features and/or combinations of such features during prosecution of the present application or of any further application derived therefrom.

CLAIMS

1. A method of manufacturing an electronic device comprising a thin-film circuit element, which method includes the steps of:

(a) directing an energy beam at a surface area of a semiconductor thin film on a substrate to crystallise at least a portion of the thin film,

(b) monitoring the surface quality of the crystallised portion of the thin film by directing light at the surface area of the crystallised portion and by detecting with a light detector the light returned by the surface area, the light detector giving an output indicative of the monitored surface quality, and

(c) setting the energy of the beam in accordance with the output from the light detector to regulate the crystallisation of a device portion of a semiconductor thin film at which the beam is subsequently directed with its set energy,

characterised in that the light detector is located at a position outside the specular reflection path of the light returned by the surface area of the crystallised portion and detects a threshold increase in intensity of the light being scattered by the surface area of the crystallised portion, which threshold increase occurs when the energy of the beam is increased sufficiently to cause an onset of surface roughening, and in that, when crystallising the device portion for the thin-film circuit element during the step (c), the energy of the beam is set to a value as determined by the detection of said threshold increase.

2. A method as claimed in Claim 1, further characterised in that the portion crystallised in step (a) is a part of the same semiconductor thin film as the device portion subsequently crystallised with the beam of set energy in step (c).

3. A method as claimed in Claim 2, further characterised by the steps of directing the energy beam at a test surface area of the semiconductor

thin film in step (a), changing the energy of the beam to the set value by monitoring the quality of the crystallised test surface area by means of the scattered light in step (b), and directing the energy beam with the set value of energy at a different surface area of the semiconductor thin film to crystallise the device portion for the thin-film circuit element.

4. A method as claimed in Claim 3, further characterised in that the test surface area is a peripheral area of the semiconductor thin film.

5. A method as claimed in any one of Claims 1 or 2 or 3 or 4, further characterised in that the light which is directed at the surface area of the crystallised portion is from a light source independent of the beam used for crystallising the thin-film portion.

6. A method as claimed in any one of Claims 1 or 2 or 3 or 4, further characterised in that the beam used for crystallising the portion of the thin film is from a laser and provides also the light which is scattered to the light detector for monitoring the surface quality in step (b).

7. A method as claimed in any one of Claims 1 to 6, further characterised in that the semiconductor thin film is of silicon having a thickness in the range of 20nm to 60nm, and in that the set value of the energy of the beam used for crystallisation in step (c) is within 60mJ.cm^{-2} of the value causing the onset of surface roughening as detected by the threshold increase in intensity of the light being scattered by the surface area of the crystallised portion.

8. A method as claimed in any one of Claims 1 to 7, further characterised in that the semiconductor thin film is of a silicon material which has substantially no damaging hydrogen content at least when crystallising the device portion of the thin film for the thin-film circuit element during the step (c).

9. Apparatus for crystallising a portion of a semiconductor thin film on a substrate comprising

a laser for generating an energy beam to crystallise the portion of the thin film,

a processing cell containing a support for mounting the substrate,

an optical system between the laser and the processing cell to direct the beam from the laser at a surface area of the thin film when the substrate is mounted in the processing cell,

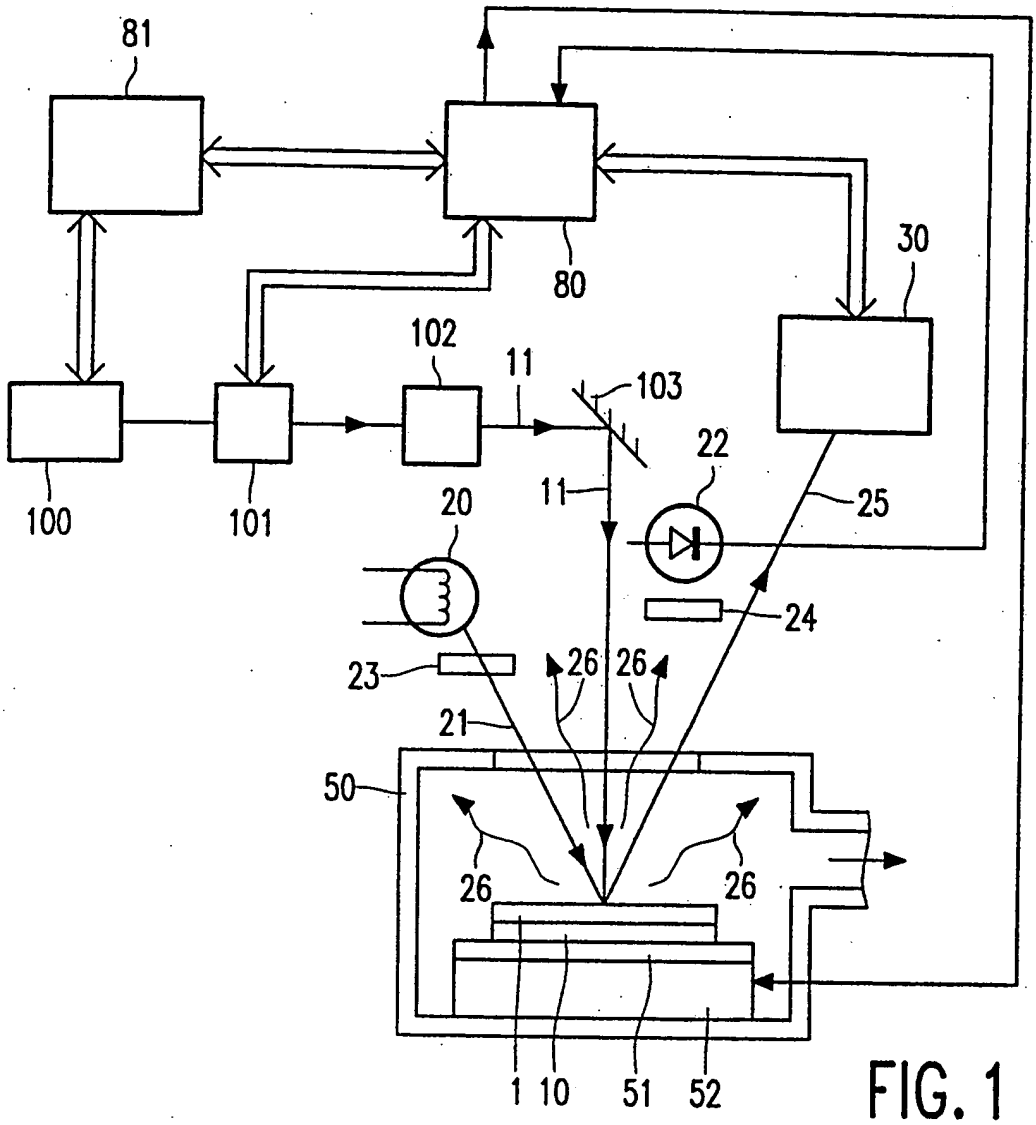
adaptor means for changing the energy of the beam incident on the film,

a light source for directing light at the surface area of the crystallised portion of the thin film, and

a light detector for detecting the light returned by the surface area, the light detector giving an output indicative of the surface quality,

characterised in that the light detector is located at a position outside the specular reflection path of the light returned by the surface area of the crystallised portion and has sufficient sensitivity to detect a threshold increase in intensity of the light being scattered by the surface area of the crystallised portion, which threshold increase occurs when the energy of the beam is increased sufficiently to cause the onset of surface roughening, and control means take an input from the output of the light detector and provide an output to the adaptor means for setting the energy of the beam to a value as determined by the detection of said threshold increase.

10. Apparatus as claimed in Claim 9, further characterised in that the adaptor means is an attenuator which is located in the path of the beam, and which forms part of the optical system between the laser and the processing cell.


81
80
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1
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51
52

FIG. 1

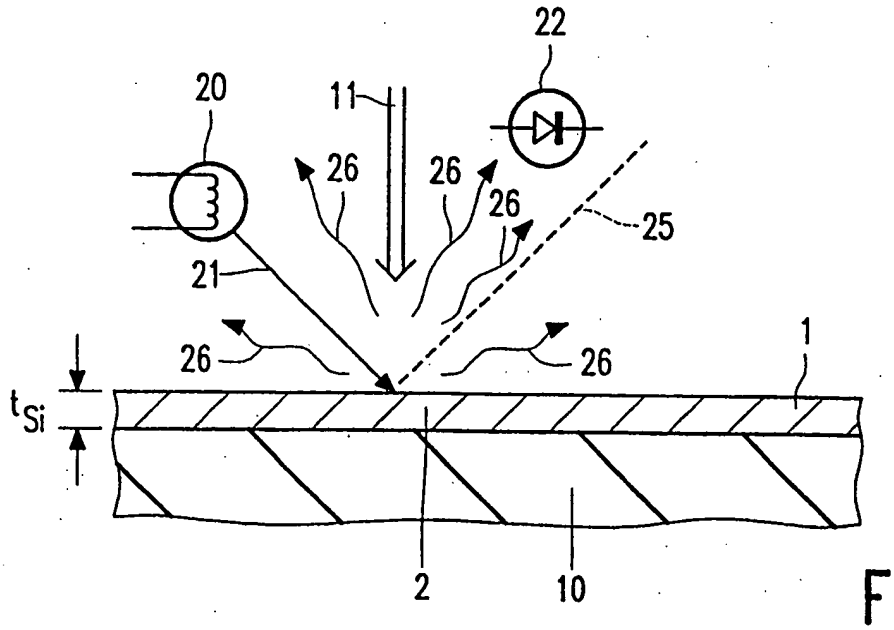

22
20
11
26
25
21
1
t_{Si}
2
10

FIG. 2

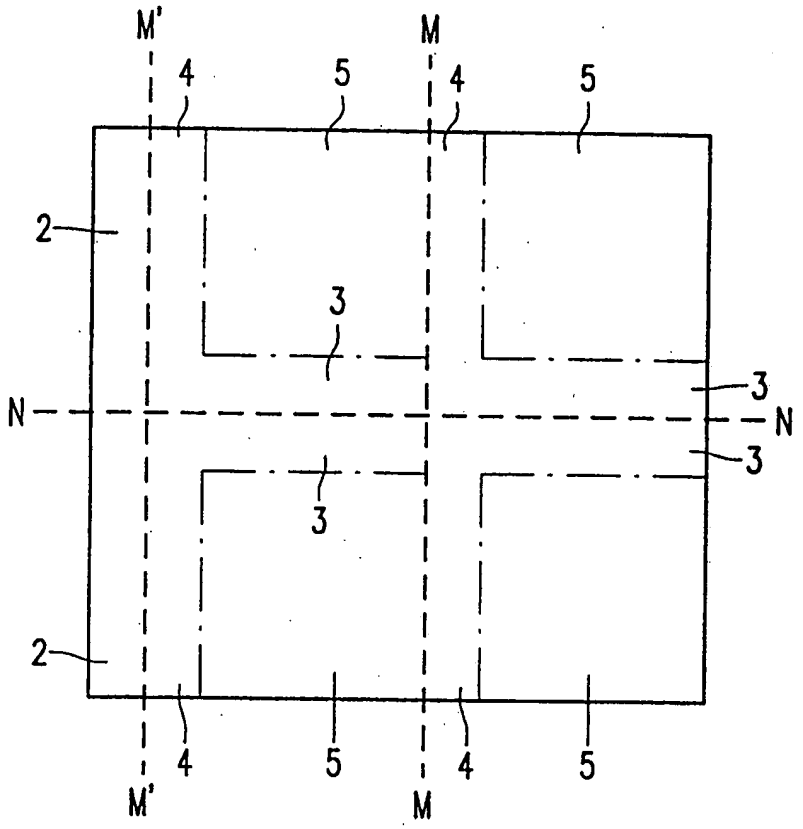


FIG. 3

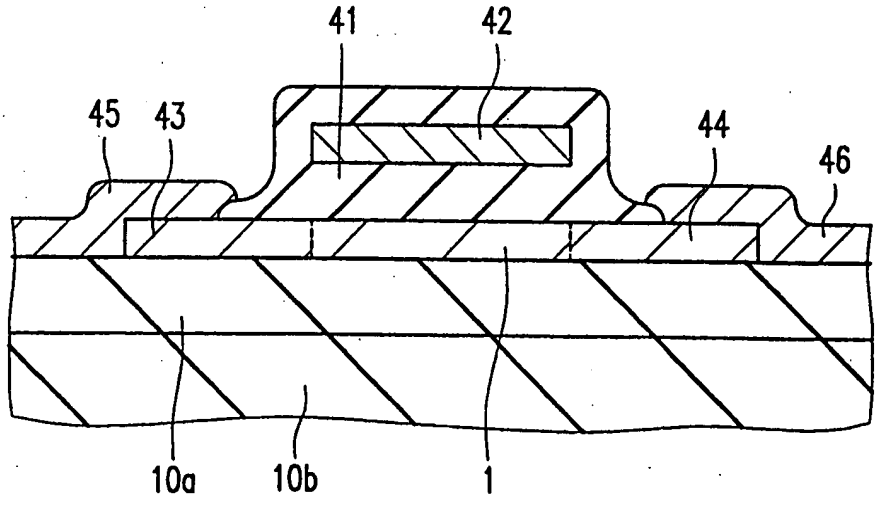


FIG. 4

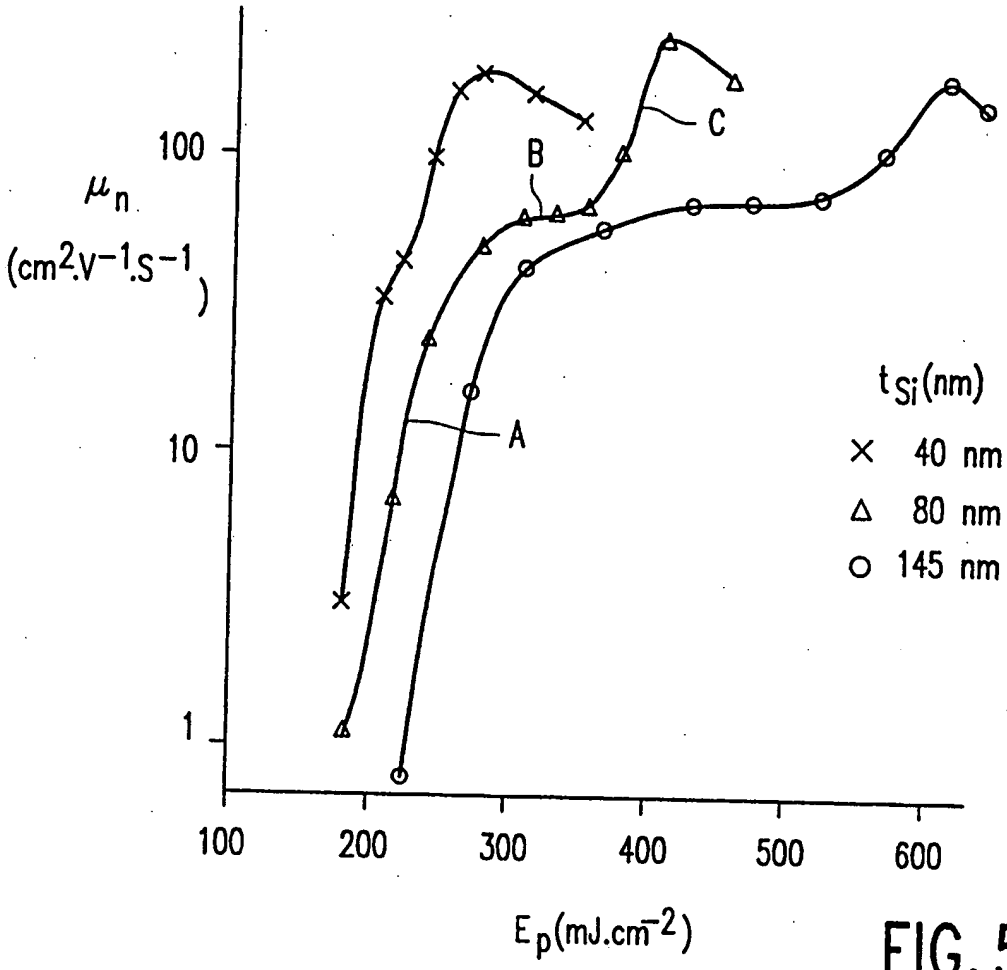
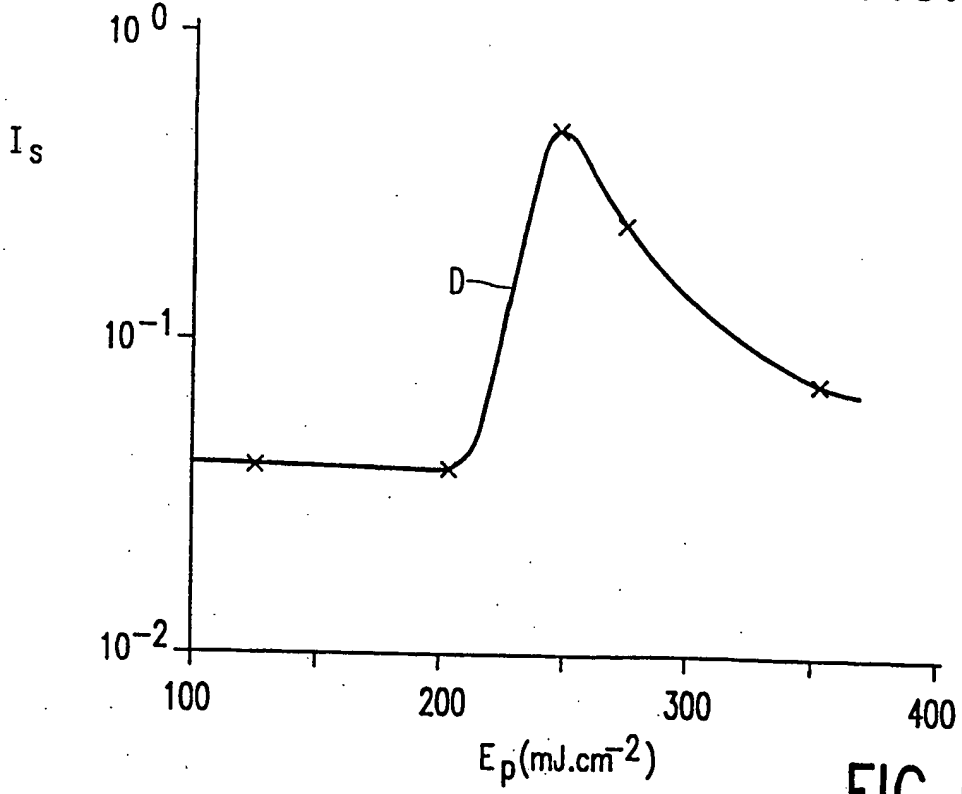

100
10
1
μ_n
$(cm^2.V^{-1}.S^{-1})$
A
B
C
t_{Si}(nm)
× 40 nm
△ 80 nm
○ 145 nm
100
200
300
400
500
600
$E_p(mJ.cm^{-2})$

FIG. 5


10^0
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10^{-2}
I_s
D
100
200
300
400
$E_p(mJ.cm^{-2})$

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/01186

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01L 21/302, H01L 21/263
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DIALOG. 2,350,434

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Solid State Phenomena, Volume 37-38, 1994, (Switzerland), S.D. Brotherton et al, "BEAM SHAPE EFFECTS WITH EXCIMER LASER CRYSTALLISATION OF PLASMA ENHANCED AND LOW PRESSURE CHEMICAL VAPOR DEPOSITED AMORPHOUS SILICON" page 299 - page 304 --	1-10
A	US 5372836 A (ISSEI IMAHASHI ET AL), 13 December 1994 (13.12.94), figure 5, abstract --	1-10
A	EP 0367624 A2 (LASA INDUSTRIES, INC.), 9 May 1990 (09.05.90), figure 1, abstract --	1-10

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 April 1998	14 -04- 1998
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM	Authorized officer

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 97/01186

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4309225 A (JOHN C.C. FAN ET AL), 5 January 1982 (05.01.82), column 2, line 50 - column 3, line 30, figures 1,7 --	1-10
A	US 4155779 A (DAVID H. AUSTON ET AL), 22 May 1979 (22.05.79), column 1, line 45 - line 57, figures 1, 2 --	1-10

INTERNATIONAL SEARCH REPORT

Information on patent family members

02/03/98

International application No.
PCT/IB 97/01186

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EP 0367624 A2	09/05/90	JP 2244779 A	28/09/90
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		FR 2434483 A,B	21/03/80
		GB 2040077 A,B	20/08/80
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		NL 7920078 A,T	30/06/80
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